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# THE JURASSIC TO PALAEOGENE STRATA IN THE NORTHERN BOUNDARY FAULT ZONE IN DEEP BOREHOLE PD-9 AT SZCZAWNICA, PIENINY KLIPPEN BELT, WEST CARPATHIANS, POLAND: BIOSTRATIGRAPHY AND TECTONIC IMPLICATIONS

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**Abstract:** The Jurassic through Palaeogene stratigraphy and tectonic structure of the PD-9 borehole at Szczawnica, Pieniny Klippen Belt, West Carpathians, Poland, is revised. The borehole was drilled in the strongly tectonized northern boundary fault zone of the Pieniny Klippen Belt, of Miocene age. Age revision is given by dinoflagellate cysts. Late Cretaceous taxa are reported from the Hałuszowa Formation. The Bryjarka Member (previously with the rank of formation) yielded rich Early Eocene (Ypresian) assemblages. Similar ones are reported from the Szczawnica Formation. A tectonic thrust sheet of the Jurassic Szlachtowa Formation (Grajcarek Unit) in the Palaeogene of the Magura Nappe is evidenced; it yielded late Toarcian–Aalenian dinoflagellate cyst assemblages. The succession of strata recorded from the PD-9 borehole shows the steep, almost vertical attitude of the Grajcarek Main Dislocation at Szczawnica, separating the structures of the Magura Nappe (to the north) and the Pieniny Klippen Belt to the south.

**Key words:** Carpathians, biostratigraphy, dinoflagellate cysts, lithostratigraphy, tectonics, Poland.

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## INTRODUCTION

The PD-9 borehole is the second deepest well after Maruszyna IG-1 (Birkenmajer and Gedl, 2012) drilled in the Pieniny Klippen Belt structure. It is located in the northern boundary fault zone of the structure, where it contacts with the Magura Nappe of the Outer (Flysch) Carpathians (Figs 1, 2). This location of the well allows study of the character of the contact between these two geological structures down to a depth of almost 1,200 m.

The PD-9 borehole was drilled in 1967–1969 (Birkenmajer *et al*., 1979; Figs 3, 4). Its purpose was the estimation of the local mineral water resources in relation to the geological structure in the subsurface. The well penetrated almost 1,200 m of steeply dipping, faulted strata of the Grajcarek Unit (Pieniny Klippen Belt) and the Magura Nappe (Outer Carpathians; Fig. 4). Four lithostratigraphic units were distinguished in the Grajcarek Unit (Birkenmajer *et al*., 1979): the Szlachtowa Formation, the Malinowa Shale Formation, the Hałuszowa Formation, and the Jarmuta Formation. The Magura Nappe is represented by the Szczawnica Formation and its new division, the Bryjarka Member. So far, the latter was distinguished at the rank of formation, but in the present account it is considered to be an intercalation in the Szczawnica Formation.

The first scientific results from the PD-9 well were elaborated by Birkenmajer *et al.* (1979), who presented a lithological description of the material drilled, the lithostratigraphic scheme and a general, geological synthesis (by K. Birkenmajer), as well as the description and age determination of the uncommon calcareous nannoplankton (by J. Dudziak), and foraminifera assemblages (by A. Jednorowska).

In this paper the authors present new data on organic-walled dinoflagellate cyst assemblages from the same set of samples studied in the seventies for calcareous nannoplankton and foraminifera. They shed a new light on some aspects of the geological structure of the area in question.

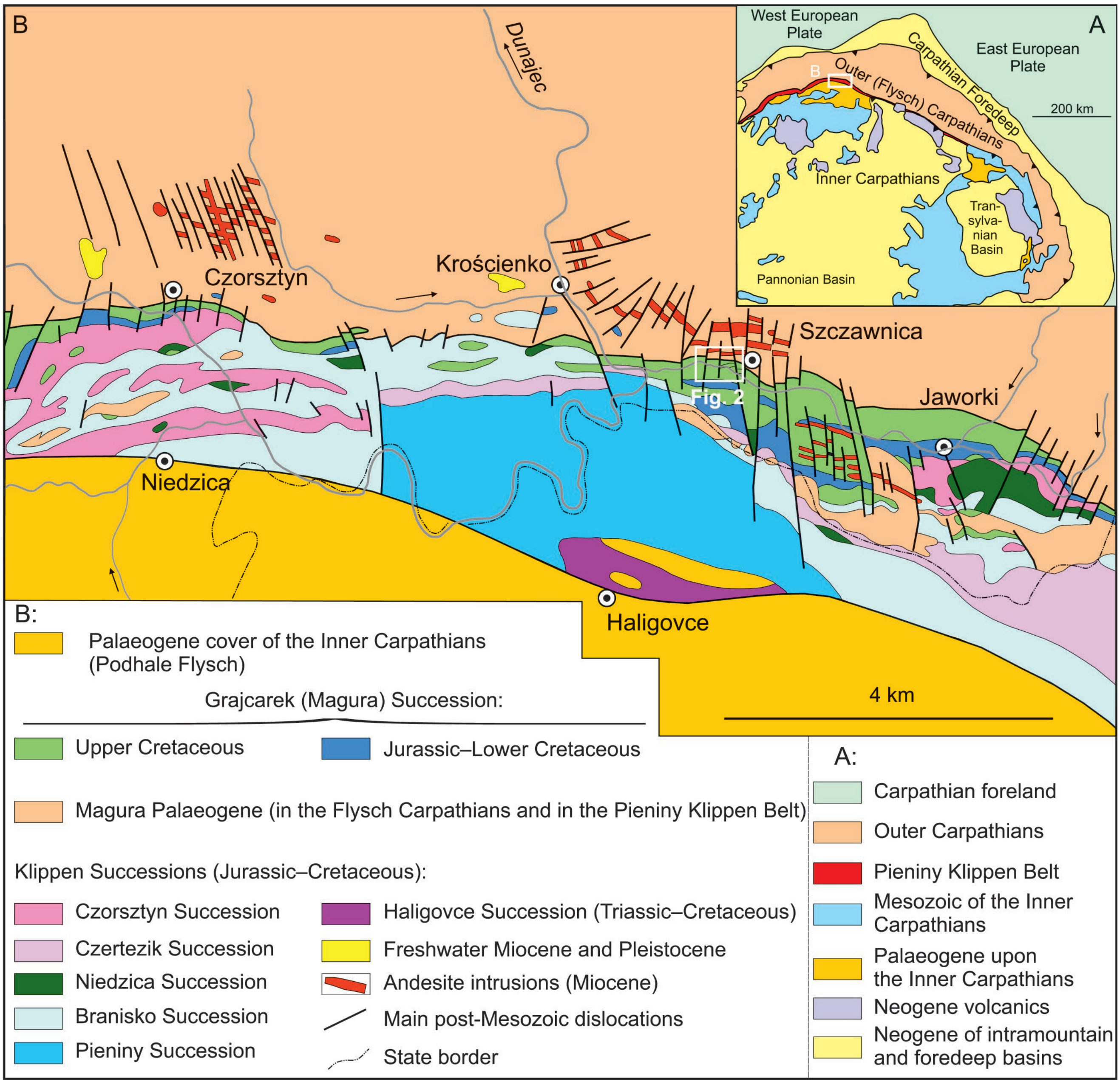


**Fig. 1.** Simplified geological structure of the central sector of the Pieniny Klippen Belt of Poland (after Birkenmajer, 1979; slightly modified and updated after Birkenmajer, 2017) and its position in the Carpathians (based on Picha, 1996; from Picha *et al*., 2006; simplified).

## GEOLOGICAL SETTING

The Pieniny Klippen Belt is a tectonic structure that separates the Inner (to the south) and the Outer Carpathians, according to Polish nomenclature. Its stratigraphic succession consists of Jurassic and Cretaceous strata. They were deposited in vast, marine basins, several hundred kilometres wide, later to be folded and squeezed to form nowadays a tectonic belt, just a few kilometres wide and spread in an arcuate manner over a distance of 600 km (Fig. 1A). The bulk of the Mesozoic strata (Lower Jurassic–Upper Cretaceous) was deposited to the south of the Czorsztyn Ridge (Pienides), the elevated element that separated the Inner and Outer Carpathian basins. To the north of the ridge, the Magura Basin existed (Outer Carpathians; Fig. 1). During the first main tectonic phase (the Laramian phase; latest Cretaceous–earliest Paleocene) the Klippen successions underwent significant folding (e.g., Birkenmajer, 1986); the same folding phase led to the tectonic incorporation of strata deposited in the southernmost part of the Magura Basin (the Grajcarek Unit; e.g., Birkenmajer and Gedl, 2017), now within the Pieniny Klippen Belt structure.

The second tectonic phase took place during the Late Oligocene–Early Miocene. The tectonic movements resulted in compressional folding, followed by the formation of strike-slip and thrust faults. At that time, the northern tectonic boundary of the Pieniny Klippen Belt, which delimits the Inner Carpathian domain from the Outer Carpathians (Magura Nappe; Fig. 1), was formed. During the Miocene, there was magmatic activity in the form of andesite intrusions.

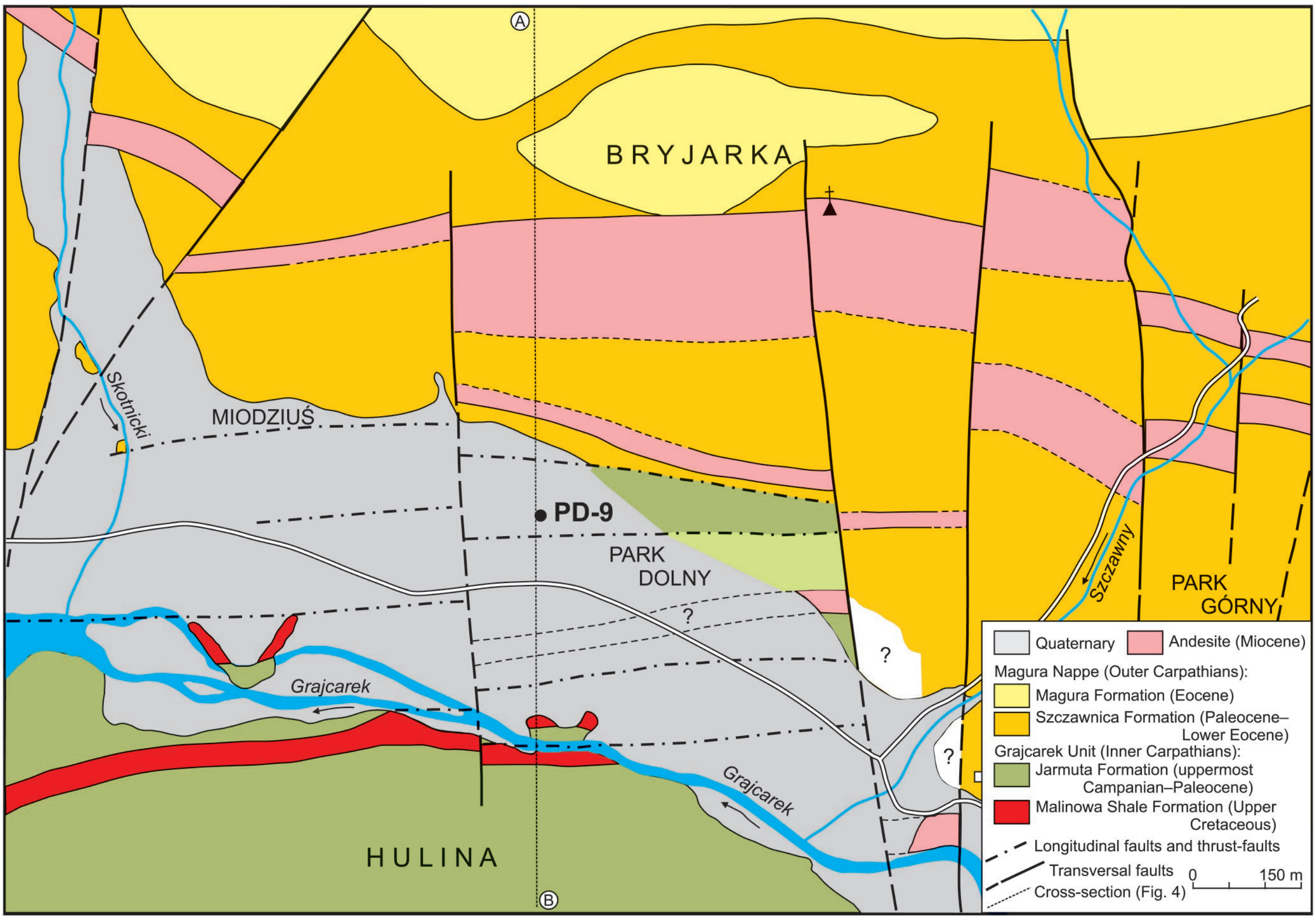


**Fig. 2.** Geological map of the northern boundary fault zone of the Pieniny Klippen Belt at Szczawnica (from Birkenmajer in Birkenmajer *et al*., 1979).

The boundary fault zone at Szczawnica, up to 2 km wide, is composed of Jurassic and Cretaceous rocks (Klippen successions and the Grajcarek Unit) and the Palaeogene of the Magura Basin. It is formed by parallel reverse faults or steeply dipping, latitudinal, south-dipping overthrusts, cut by and displaced along transverse faults (Fig. 2). The fault system was rejuvenated by Miocene andesite intrusions, with which mineral waters are connected. Estimates of the latter resource were the basis for the drilling of several boreholes, including the deepest one, the PD-9 well. The boundary itself (the Grajcarek Dislocation; Gołąb, 1948) runs in the vicinity of Szczawnica, approximately along the southern slopes of Jarmuta Mt. There are different tectonic styles on opposite sides of the feature. The southern side (Pieniny Klippen Belt) is composed of steeply dipping folds and overthrusts involving Jurassic, Cretaceous and Paleocene strata (Szlachtowa Formation, Malinowa Shale Formation, Hałuszowa Formation, and Jarmuta Formation). The northern side represents the Magura Nappe and is built of gently folded Palaeogene strata.

The surface geology of the boundary fault zone at Szczawnica was studied in detail by Birkenmajer (e.g., 1956a, b, 1957, 1958, 1962, 1979). These results were supplemented by subsurface data from numerous boreholes drilled at Szczawnica. Particularly important data were obtained from the 1,200-m-deep borehole PD-9 (Birkenmajer *et al*., 1979); they showed a complicated structure of Jurassic, Cretaceous and Palaeogene strata, dipping steeply and commonly folded (see comparison in Figure 4).

## MATERIAL

Fifty-three samples from the PD-9 borehole were examined for dinoflagellate cysts. These samples, stored in the Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Kraków, previously had been studied for calcareous nannoplankton and foraminifera by Birkenmajer *et al*. (1979). Most of samples studied are bailer samples. Only five samples from the Bryjarka Member are from cores. Precise sample depth coordinates are rare; commonly only depths of intervals cored are given. Below, a list of samples studied is given.

### Grajcarek Unit

**The Jarmuta Formation.** Two thrust sheets of this unit occur at depths of 68.5–142.3 m and 156.5–223.5 m. Two samples of fine-grained matrix were examined: 90.6–92.1 m and 182.5–185.2 m.

**The Malinowa Shale Formation.** Red shale of this lithostratigraphic unit occurs in several intervals at the following depths: 30.0–68.5 m, 142.3–143.8 m, 257.6–259.1

m, 270.6–283.5 m, 352.0–415.0 m, and 855–866 m. Seven samples were examined: 45–47.3 m, 142.3–143.8 m, 257.6–259.1 m, 274.5–278.6 m, 372.2–375.5 m, 855.4–859.6 m, and 859.6–864 m.

**The Hałuszowa Formation.** This unit occurs in two thrust sheets at depths of 259.1–270.6 m and 283.5–352.0 m. A total of six samples were examined, two samples from the upper thrust sheet (263.1–266.7 m and 266.7–270.6 m) and four samples from the lower thrust sheet (285.8–289.8 m, 292.7–297.8 m, 306.7–310.6 m, and 333.1–337.5 m).

**The Szlachtowa Formation.** This unit was recognized by Birkenmajer *et al*. (1979) at a depth of 702.5–855 m. Present data show that only upper part of this interval represents the Szlachtowa Formation – two samples 707.1–710.4 m and 710.4–716.4 m. The lower interval represents Palaeogene strata of the Magura Nappe.

### Magura Nappe

**The Bryjarka Member** occurs at a depth of 415.0–702.0 m. Eighteen samples were taken (C stands for core samples): 418.4–421.5 m, 426.3–431.1 m (C), 431.1–436.5 m, 467.8–469.5 m (C), 469.5–473.1 m, 505.1–509.7 m (C), 540.2–544.5 m (C), 569.8–575.1 m (C), 584.3–589.1 m, 604–606 m, 625.7 m, 631.0 m, 635.5 m, 638.1 m, 642.6 m, 653.1 m, 662.3–668.8 m, and 691.8–696.6 m.

**The Szczawnica Formation.** This unit occurs at the base of the borehole below 866 m. Eight samples were taken: 866–869.0 m, 920.0–924.6 m, 924.6–929.6 m, 946.3–946.5 m, 971.1–972.1 m, 981.7–984.3 m, 987.9–991.1 m, and 1002.4–1006.4 m.

Ten samples from an interval, formerly assigned to the Szlachtowa Formation (Birkenmajer *et al*., 1979), represent Palaeogene strata, most likely of the Szczawnica Formation: 729.1–734.0 m, 738.4–744.3 m, 765.2–771.2 m, 779.1–784.6 m, 784.6–790.7 m, 790.7–796.8 m, 801.3–805.8 m, 805.8–810.6 m, 827.0–831.6 m, and 846.3–850.8 m.

## METHODS

The samples were processed following palynological procedure, including 38% hydrochloric acid (HCl) treatment, 40% hydrofluoric acid (HF) treatment, heavy liquid ($ZnCl_2$+HCl; density 2.0 g/cm$^3$) separation, ultrasound for 10–15 s and sieving at 15 µm on a nylon mesh. No oxidation in fuming nitric acid ($HNO_3$) was applied. The quantity of rock processed was 20 g for each sample. A single slide was made from each sample using glycerine jelly as a mounting medium; all dinoflagellate cysts from each slide were determined qualitatively using a Zeiss Axiolab microscope. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Kraków.

## RESULTS

The dinoflagellate cyst distribution in the PD-9 borehole is shown in Table 1. They are illustrated in Figures 5–12. Dark shale of the Jarmuta Formation (two samples) yielded only small amounts of black, opaque phytoclasts. Seven samples of the red shale of the Malinowa Shale Formation were found to be barren.

The palynofacies of the dark shale of the Hałuszowa Formation consists mainly of black, opaque phytoclasts. Samples from depths of 306.7–310.6 m and 292.7 m contain up to 10% of dark brown cuticles. Very rare dinoflagellate cysts, commonly single specimens per sample, occur in all samples from this lithostratigraphic unit, except for two samples from depths of 263.1–266.7 m and 333.1–337.5 m (Fig. 5). Dinoflagellate cysts are dark brown but generally well preserved (*Spiniferites* sp., *Circulodinium*? sp., *Pterodinium* sp.). A sample from a depth of 292.7–297.8 m yielded variously preserved dinoflagellate cysts: the peridinioids, *Dinogymnium* and *Spiniferites*, are pale coloured and very well preserved, whereas *Cordosphaeridium fibrospinosum* and *Glaphyrocysta* sp. are much darker (Fig. 5).

Eighteen samples of the dark grey and greenish shale of the Bryjarka Member (415.00–702.00 m) yielded palynofacies composed of terrestrial palynodebris (various proportions of dark brown cuticles, dark brown and black, opaque phytoclasts) associated with dinoflagellate cysts, which are generally rare in samples with frequent black, opaque phytoclasts (426.3–431.1 m, 540.2–544.5 m, 638.1 m, 642.6 m, 662.3–668.8 m), and frequent (even up to 20%) in samples with a higher proportion of cuticles. The palynofacies of some samples, however, consists of cuticles and rare dinoflagellate cysts (431.1–436.5 m, 584.3–589.1 m).

Dinoflagellate cysts from the Bryjarka Member are moderately preserved (Figs 6–9). Most of them are brownish and compressed, but their structure is relatively well preserved. Some specimens, however, show a much higher degree of alteration reflected mainly in darker colouration and poorer preservation of wall structures. Both preservation types occur commonly in the same samples.

The diversity of dinoflagellate cyst assemblages correlates with palynofacies. Peridinioid-dominated assemblages occur generally in samples that yielded lower amounts of organic particles, dominated by black opaque phytoclasts. Taxonomically richer assemblages, composed mainly of gonyaulacoids (areoligeraceans and *Homotryblium*), occur in samples with high amounts of organic particles, dominated by cuticles and dark brown palynodebris.

The topmost sample from a depth of 418.4–421.5 m yielded a rich and diversified assemblage with frequent areoligeraceans, such as *Areoligera*, *Glaphyrocysta*, *Adnatosphaeridium*. *Apectodinium* and *Homotryblium tenuispinosum* are also common.

Dinoflagellate cysts from the two lower samples (426.3–431.1 m, 431.1–436.5 m) are dominated by peridinioids, mainly *Apectodinium* (plus rare *Deflandrea* and Wetzelielloideae). The peridiniod proportion is the highest, almost 100%, in the sample 426.3–431.1 m; the palynofacies is dominated by black, opaque phytoclasts. Subordinate, infrequent gonyaulacoids (*Polysphaeridium*, *Homotryblium*, and *Spiniferites*) occur in the second sample, with a palynofacies richer in cuticles.

Three samples from the depth interval 467–509 m yielded relatively diversified dinoflagellate cyst assemblages, composed mainly of gonyaulacoids, with frequent *Homotryblium*, *Areoligera* and *Glaphyrocysta* (467.8–469.5 m),

**Table 1**

Distribution of dinoflagellate cysts in the PD-9 borehole. Abbreviations: M.F. – Malinowa Shale Formation. J.F. – Jarmuta Formation. H.F. – Hałuszowa Formation. S.F. – Szlachtowa Formation. ? – uncertain occurrence.

| Lithostratigraphy | Taxon<br>Sample depth [m] | 1 *Spiniferites* sp. | 2 *Ovoidinium*? sp. | 3 *Pterodinium* sp. | 4 *Circulodinium*? sp. | 5 *Muderongia*? sp. | 6 *Dinogymnium* sp. | 7 *Cordosphaeridium fibrospinosum* | 8 *Glaphyrocysta* sp. | 9 *Yolkinigymnium* sp. | 10 *Alterbidinium*? sp. | 11 *Phthanoperidinium delicatum* | 12 *Homotryblium tenuispinosum* | 13 *Adnatosphaeridium vittatum* | 14 *Polysphaeridium zoharyi* | 15 *Apectodinium* sp. | 16 *Isabelidinium*? sp. | 17 *Areoligera* sp. | 18 *Apectodinium homomorphum* | 19 *Operculodinium microtriainum* | 20 *Achilleodinium*? sp. | 21 *Wetzeliella* sp. | 22 *Glaphyrocysta laciniiformis* | 23 *Glaphyrocysta spineta* | 24 *Thalassiphora patula* | 25 *Apectodinium parvum* | 26 *Cordosphaeridium* sp. | 27 *Systematophora* sp. | 28 *Apteodinium* sp. | 29 *Wetzeliella meckelfeldensis* | 30 *Rhombodinium*? sp. | 31 *Ynezidinium brevisulcatum* | 32 *Apectodinium summissum* | 33 *Lingulodinium machaerophorum* | 34 *Adnatosphaeridium multispinosum* | 35 *Lejeunecysta* sp. | 36 *Homotryblium caliculum* | 37 *Tectatodinium*? sp. | 38 *Achomosphaera alcicornu* | 39 *Glaphyrocysta ordinata* | 40 *Adnatosphaeridium* cf. *multispinosum* | 41 *Operculodinium* sp. | 42 *Apectodinium quinquelatum* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M.F. | 45–47.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J.F. | 90.6–92.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M.F. | 142.3–143.8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J.F. | 182.5–185.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M.F. | 257.6–259.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H.F. | 263.1–266.7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 266.7–270.6 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M.F. | 274.5–278.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Hałuszowa Formation | 285.8–289.8 | 3 | | | 1 | 1 | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 292.7–297.8 | 5 | 1 | | | | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 306.7–310.6 | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 333.1–337.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M.F. | 372.2–375.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bryjarka Member | 418.4–421.5 | 4 | | | | | | 1 | 12 | | | 1 | 20 | 7 | 2 | 5 | 2 | 25 | 19 | 3 | 1 | 1 | 8 | 1 | 4 | 7 | 2 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 5 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | |
| | 426.3–431.1 | | | | | | | | | | | | | | | 19 | 1 | | 8 | | | | | | | 12 | | | | | | | 2 | | | | | | | | | 1 | 2 |
| | 431.1–436.5 | 9 | | | | | | | | | | | | | 8 | 3 | | 10 | 18 | | | | | | | 21 | | | | | | | | | 1 | | | | | | | | |
| | 467.8–469.5 | 10 | | | | | | | | | | | 25 | | 2 | | | 29 | 3 | | | 1 | | | | | | | | 1 | | | | | 1 | | | | | | | | |
| | 469.5–473.1 | 61 | | | | | | | 2 | | | 2 | 64 | | 9 | | 2 | 11 | 7 | | | | | 1 | 1 | | | | | | | | | 3 | 6 | | | | | | | 28 | |
| | 505.1–509.7 | 6 | | | | | | | | | | | 33 | | 2 | | 3 | 72 | | | | 2 | | | 1 | | | | 1 | | 1 | 1 | | | | | | | 1 | 1 | | 12 | |
| | 540.2–544.5 | 2 | | | | | | | | | | | | | | | | 23 | | | | 1 | | | | | | | | | | 1 | | | | | | | | | | | |
| | 569.8–575.1 | 28 | | | | | | | 2 | | | 3 | 37 | 1 | 1 | 8 | 6 | 34 | 5 | | | 14 | | | | | | | | | | | | | | 3 | | | | | | 15 | 7 |
| | 584.3–589.1 | 4 | | | | | | | | | | | | | | | | | 5 | | | | | | | | | | | | | | | | | | | | | | | | |
| | 604–606 | 3 | | | | | | | | | | | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| | 625.7 | | | 1 | | | | | ? | | | | ? | | | | 7 | 5 | | | | | | | | | | | | | | | | | | | | ? | | | | | |
| | 631.0 | | | | | | | | | | | | | | | | 1 | 5 | 2 | | | 1 | | | 1 | | | | | | | | | | | | | | | | | | |
| | 635.5 | 12 | | | | | | | | | | 1 | | | 2 | | | 51 | 3 | | | | | | 1 | | | | 1 | | | | | | | | | | | | | 2 | |
| | 638.1 | | | | | | | | 1 | | | | 2 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 642.6 | | | | | | | | | | | | | | 5 | | | 10 | 4 | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| | 653.1 | 5 | | | | | | | | | | | 12 | | 41 | | 2 | 116 | | | | 1 | | | | | | | | | | | | | | | | | | | | 1 | |
| | 662.3–668.8 | 2 | | | | | | | 3 | | | 1 | 1 | | | | 1 | 12 | | | | | | | | | | | | | | | | | | 1 | | | | 1 | | | |
| | 691.8–696.6 | 5 | | | | | | | 6 | | | | 3 | ? | 1 | | 2 | 189 | | | | | | | | | 1 | | | | | | | | 2 | | | | | | | 3 | |
| S.F. | 707.1–710.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 710.4–716.4 | | | | | | | | | | | | 1 | | | | | 1 | | | | | | | | | | | | | | | | | | 1 | | | | | | | |
| Szczawnica Formation | 729.1–734 | | | | | | | | | | | | | | | | | 59 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 738.4–744.3 | | | | | | | | 2 | | | | 12 | ? | 2 | | | 68 | | 1 | | 1 | | | ? | | | | | | | | | | | | | | | | | | |
| | 765.2–771.2 | | | | | | | | 1 | | | | 4 | | | 4 | | 5 | | | | 3 | | | | | | | ? | ? | | | | | | | | | | | | | |
| | 779.1–784.6 | | | | | | | | | | | | ? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ? | 1 |
| | 784.6–790.7 | | | | | | | | 1 | | | | | | | 3 | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | |
| | 790.7–796.8 | 1 | | | | | | | | | | | | | | 8 | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 |
| | 801.3–805.8 | | | | | | | | | | | | 1 | | | | | 5 | | | | | | | 1 | | | | | | | | | | | | | | | 1 | | | |
| | 805.8–810.6 | 5 | | | 1 | | | | 3 | | 1 | | 5 | | 1 | 6 | | 2 | 5 | 1 | | 1 | | | | | ? | | | | | | | | | 4 | | | | | | | |
| | 827–831.6 | | | | | | | | | | | | 1 | | | | | 2 | | | | 1 | | | | | | | | | | | | | | | | | | | | | |
| | 846.3–850.8 | 4 | | | | | | | | | | | | | 2 | | | 2 | 3 | | | | | | | | | | | | | | | | | | | | 1 | | | 11 | |
| M.F. | 855.4–859.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 859.6–864 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Szczawnica Formation | 866–869 | 15 | | | | | | 1 | | | | 4 | 5 | | 1 | 6 | 1 | 18 | 11 | 1 | | | | | | 2 | | | | | | | | | | | | | | | | 8 | |
| | 920–924.6 | | | | | | | | | | | | | | | 5 | | 7 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| | 924.6–929.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 946.3–946.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 971.1–972.1 | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 981.7–984.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 987.9–991.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1002.4–1006.4 | | | | | | | | | | | | | | | | | | | | | | | | | | ? | | | | | | | | | | | | | | | | |

| Lithostratigraphy | Taxon<br>Sample depth [m] | 43 *Rhombodinium* sp. A | 44 *Dracodinium waipawaense* | 45 *Homotryblium pallidum* | 46 *Gonyaulacysta* sp. | 47 *Glaphyrocysta exuberans* | 48 *Homotryblium abbreviatum* | 49 *Diphyes colligerum* | 50 *Dracodinium* sp. | 51 *Cordosphaeridium inodes* | 52 *Impletosphaeridium* sp. | 53 *Heslertonia heslertonensis* | 54 *Dracodinium laszczynskii* | 55 *Polysphaeridium subtile* | 56 *Phthanoperidinium* sp. | 57 *Melitasphaeridium pseudorecurvatum* | 58 *Escharisphaeridia*? sp. | 59 *Biconidinium longissimum* | 60 *Cribroperidinium* sp. | 61 *Deflandrea* sp. | 62 *Rhombodinium* sp. | 63 *Thalassiphora* sp. | 64 *Impagidinium velorum* | 65 *Trithyrodinium*? sp. | 66 *Heteraulacacysta leptalea* | 67 *Deflandrea*? sp. | 68 *Wetzeliella astra* | 69 *Hystrichokolpoma* sp. | 70 *Deflandrea oebisfeldensis* | 71 *Operculodinium divergens* | 72 *Spinidinium* sp. | 73 *Nematosphaeropsis reticulensis* | 74 *Rottnestia borussica* | 75 *Deflandrea leptodermata* | 76 *Deflandrea eocenica* | 77 *Rhombodinium* cf. *longimanum* | 78 *Senegalinium*? sp. | 79 *Hystrichodinium*? sp. | 80 *Wetzeliella unicaudalis* | 81 *Impagidinium* sp. | 82 *Melitasphaeridium asterium* | 83 *Dinogymnium acuminatum* | 84 *Dapsilidinium* sp. | 85 *Cordosphaeridium*? *solidospinosum* | 86 *Dracodinium solidum* | 87 *Nannoceratopsis dictyambonis* | 88 *Nannoceratopsis gracilis* | 89 *Kallosphaeridium*? sp. | 90 *Kallosphaeridium praussii* | 91 *Batiacasphaera* sp. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M.F. | 45–47.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J.F. | 90.6–92.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M.F. | 142.3–143.8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J.F. | 182.5–185.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M.F. | 257.6–259.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H.F. | 263.1–266.7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 266.7–270.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M.F. | 274.5–278.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Hałuszowa Formation | 285.8–289.8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 292.7–297.8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 306.7–310.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 333.1–337.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M.F. | 372.2–375.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bryjarka Member | 418.4–421.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 426.3–431.1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 431.1–436.5 | | 1 | 2 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 467.8–469.5 | | | 2 | | 9 | 29 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 469.5–473.1 | | | | | 1 | 45 | | | | 1 | 1 | 3 | 5 | 1 | 4 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 505.1–509.7 | | | | | | | | | | | | | | | 1 | | | | 5 | 1 | 4 | 1 | 1 | 2 | 10 | 3 | 1 | 1 | 2 | | | | | | | | | | | | | | | | | | | | |
| | 540.2–544.5 | | | | | | | | | | | | | | | | | | | 48 | | | | | | | | | 1 | | 1 | | | | | | | | | | | | | | | | | | | |
| | 569.8–575.1 | | | | | | | | | 1 | | | | | 1 | | | | | 18 | 2 | 1 | | | | | 1 | 1 | | 3 | | 1 | 1 | 3 | 2 | 1 | 1 | | | | | | | | | | | | | |
| | 584.3–589.1 | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| | 604–606 | | | | | | | | | | | | | | | | | | | 9 | 1 | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | |
| | 625.7 | | | | | | | | | | | | | | | | | | | 71 | | | | | | | | | | | | | | | 3 | | | | | | | | | | | | | | | |
| | 631.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 635.5 | | | | | | | | | | | | | | | 1 | | | | 2 | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | |
| | 638.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 642.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| | 653.1 | | | | | | | | | 1 | | | | 5 | | 1 | | | | 6 | | | | | | | | | | | | 1 | | | | | | | | 1 | 1 | 1 | | | | | | | | |
| | 662.3–668.8 | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| | 691.8–696.6 | | | | | | 1 | | | | | | | | | | | | | 5 | | | | | | | | | | | | 1 | | | | | | | | | | | 1 | 1 | ? | | | | | |
| S.F. | 707.1–710.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 76 | 23 | 12 | 3 | 2 |
| | 710.4–716.4 | | | | | | | | | | | | | 1 | | | | | | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | 13 | | | |
| Szczawnica Formation | 729.1–734 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 738.4–744.3 | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 765.2–771.2 | | | | | | | | | 1 | | | | | | | | | | | | 1 | | | | | ? | | | 1 | | | | | | | | | | | | | | | | | | | | |
| | 779.1–784.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 784.6–790.7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 790.7–796.8 | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 801.3–805.8 | | | | | | 1 | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 805.8–810.6 | | | | | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | 1 | | 1 | | | | | | | |
| | 827–831.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 846.3–850.8 | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| M.F. | 855.4–859.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 859.6–864 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Szczawnica Formation | 866–869 | | | | | | 1 | | 1 | | | | | | | | | | | | 1 | 1 | | | | | | | | 1 | 1 | | | | | | | | | | | | | | | | | | | |
| | 920–924.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 924.6–929.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 946.3–946.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 971.1–972.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 981.7–984.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 987.9–991.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1002.4–1006.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ? |

| 92 *Dissiliodinium* sp. | 93 *Nannoceratopsis spiculata* | 94 *Nannoceratopsis raunsgaardii* | 95 *Nannoceratopsis* sp. | 96 *Phallocysta elongata* | 97 *Phallocysta* sp. | 98 *Areoligera medusettiformis* complex | 99 *Palaeocystodinium golzowense* | 100 *Apectodinium* cf. *homomorphum* | 101 *Wilsonidinium*? sp. | 102 *Dracodinium condylos* | 103 *Odontochitina* sp. | 104 *Subtilisphaera*? sp. | 105 *Lithodinia* sp. | 106 *Spiniferites pseudofurcatus* | 107 *Distatodinium ellipticum* | 108 *Eocladopyxis*? sp. | 109 *Palaeohystrichophora infusorioides* | 110 *Surculosphaeridium* sp. | 111 *Wilsonidium intermedium* | 112 *Rhiptocorys* sp. | Taxon<br>Sample depth [m] | Lithostratigraphy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | 45–47.3 | M.F. |
| | | | | | | | | | | | | | | | | | | | | | 90.6–92.1 | J.F. |
| | | | | | | | | | | | | | | | | | | | | | 142.3–143.8 | M.F. |
| | | | | | | | | | | | | | | | | | | | | | 182.5–185.2 | J.F. |
| | | | | | | | | | | | | | | | | | | | | | 257.6–259.1 | M.F. |
| | | | | | | | | | | | | | | | | | | | | | 263.1–266.7 | H.F. |
| | | | | | | | | | | | | | | | | | | | | | 266.7–270.6 | |
| | | | | | | | | | | | | | | | | | | | | | 274.5–278.6 | M.F. |
| | | | | | | | | | | | | | | | | | | | | | 285.8–289.8 | Hałuszowa Formation |
| | | | | | | | | | | | | | | | | | | | | | 292.7–297.8 | |
| | | | | | | | | | | | | | | | | | | | | | 306.7–310.6 | |
| | | | | | | | | | | | | | | | | | | | | | 333.1–337.5 | |
| | | | | | | | | | | | | | | | | | | | | | 372.2–375.5 | M.F. |
| | | | | | | | | | | | | | | | | | | | | | 418.4–421.5 | Bryjarka Member |
| | | | | | | | | | | | | | | | | | | | | | 426.3–431.1 | |
| | | | | | | | | | | | | | | | | | | | | | 431.1–436.5 | |
| | | | | | | | | | | | | | | | | | | | | | 467.8–469.5 | |
| | | | | | | | | | | | | | | | | | | | | | 469.5–473.1 | |
| | | | | | | | | | | | | | | | | | | | | | 505.1–509.7 | |
| | | | | | | | | | | | | | | | | | | | | | 540.2–544.5 | |
| | | | | | | | | | | | | | | | | | | | | | 569.8–575.1 | |
| | | | | | | | | | | | | | | | | | | | | | 584.3–589.1 | |
| | | | | | | | | | | | | | | | | | | | | | 604–606 | |
| | | | | | | | | | | | | | | | | | | | | | 625.7 | |
| | | | | | | | | | | | | | | | | | | | | | 631.0 | |
| | | | | | | | | | | | | | | | | | | | | | 635.5 | |
| | | | | | | | | | | | | | | | | | | | | | 638.1 | |
| | | | | | | | | | | | | | | | | | | | | | 642.6 | |
| | | | | | | | | | | | | | | | | | | | | | 653.1 | |
| | | | | | | | | | | | | | | | | | | | | | 662.3–668.8 | |
| | | | | | | | | | | | | | | | | | | | | | 691.8–696.6 | |
| 8 | 1 | 1 | 9 | | | | | | | | | | | | | | | | | | 707.1–710.4 | S.F. |
| | | | 3 | 11 | 4 | | | | | | | | | | | | | | | | 710.4–716.4 | |
| | | | | | | | | | | | | | | | | | | | | | 729.1–734 | Szczawnica Formation |
| | | | | | | 7 | | | | | | | | | | | | | | | 738.4–744.3 | |
| | | | | | | | 1 | 2 | | | | | | | | | | | | | 765.2–771.2 | |
| | | | | | | | | | | | | | | | | | | | | | 779.1–784.6 | |
| | | | | | | | | | 1 | | | | | | | | | | | | 784.6–790.7 | |
| | | | | | | | | | | | | | | | | | | | | | 790.7–796.8 | |
| | | | | | | | | 2 | | 1 | | | | | | | | | | | 801.3–805.8 | |
| | | | | | | | | 2 | | | 2 | 1 | 1 | | | | | | | | 805.8–810.6 | |
| | | | 1 | | | | | | | | | | | ? | ? | | | | | | 827–831.6 | |
| | | | | | | | | 1 | | | | | | | ? | 14 | | | | | 846.3–850.8 | |
| | | | | | | | | | | | | | | | | | | | | | 855.4–859.6 | M.F. |
| | | | | | | | | | | | | | | | | | | | | | 859.6–864 | |
| | | | | | | | | 1 | | | | | | | | 1 | 2 | 1 | 1 | | 866–869 | Szczawnica Formation |
| | | | | | | | | | | | | | | | | | | | | | 920–924.6 | |
| | | | | | | | | | | | | | | | | | | | | | 924.6–929.6 | |
| | | | | | | | | | | | | | | | | | | | | | 946.3–946.5 | |
| | | | | | | | | | | | | | | | | | | | | | 971.1–972.1 | |
| | | | | | | | | | | | | | | | | | | | | | 981.7–984.3 | |
| | | | | | | | | | | | | | | | | | | | | | 987.9–991.1 | |
| | | | | | | | | | | | | | | | | | | | | 1 | 1002.4–1006.4 | |

**Fig. 3.** The PD-9 borehole (photographs taken in 1969; A and B by K. Birkenmajer, C by an unknown author). **A.** A view on the PD-9 oil rig. **B.** Drilling of the PD-9 well. **C.** Drilling company team; senior author – K. Birkenmajer, second from right.

*Homotryblium*, *Spiniferites* and *Operculodinium* (469.5––473.1 m), and *Areoligera* and *Homotryblium* in the sample from a depth of 505.1–509.7 m.

A different assemblage, dominated by *Deflandrea*, with subordinate *Areoligera*, was found in the following sample from a depth of 540.2–544.5 m. This peridinioid-dominated assemblage again is associated with low amounts of organic particles composed almost entirely of black, opaque phytoclasts.

Sample 569.8–575.1 m yielded large amounts of cuticle-dominated organic particles and up to 15% of the diversified dinoflagellate cyst assemblage. It is composed predominantly of gonyaulacoids (*Areoligera*, *Homotryblium*, *Spiniferites*, and *Operculodinium*), but Wetzelielloideae and *Deflandrea* are also present.

The following four samples from the interval 584–631 m yielded highly disintegrated black particles and rare dinoflagellate cysts; most frequent are peridinioids, which are most common in the sample from a depth of 625.7 m, where *Deflandrea* predominates. A more diversified and gonyaulacoid-dominated assemblage was found in the sample from a depth of 635.5 m, whereas gonyaulacoid-dominated, but very low-frequency assemblages occur in following samples 638.1 m and 642.6 m. A much richer, but also gonyaulacoid-dominated assemblage was found in the sample from a depth of 653.1 m; here, an assemblage dominated by *Areoligera* (up to 60%), *Polysphaeridium* (30%) and *Homotryblium* is associated with a palynofacies composed chiefly of high amounts of cuticles.

The two lowermost samples from the Bryjarka Member yielded various palynofacies: the sample from a depth of 662.3–668.8 m yielded small amounts of black phytoclasts and rare dinoflagellate cysts, whereas the sample from a depth of 691.8–696.6 m contains large amounts of palynodebris and up to 20% of dinoflagellate cysts. The assemblage is composed almost entirely of gonyaulacoids, dominated at 90% by *Areoligera* (representing the *A. medusettiformis* complex; see chapter *Selected taxonomy*).

Twelve samples from the 702.50–855 m interval, previously assigned to the Szlachtowa Formation (Birkenmajer *et al.*, 1979), yielded two different dinoflagellate cyst assemblages.

The two uppermost samples (710.4–716.4 m and 707.1––710.4 m) yielded Jurassic taxa (Fig. 10). The higher sample contains exclusively Jurassic species, whereas in the lower sample Jurassic specimens are associated with infrequent, but very well preserved Palaeogene species. The sample from a depth of 707.1–710.4 m contains a very rich dinoflagellate cyst assemblage (*Nannoceratopsis dictyambonis* is most frequent), composed of yellow-brownish, relatively well preserved forms; some thick-walled specimens of *Nannoceratopsis gracilis* are darker coloured. The sample from a depth of 710.4–716.4 m yielded an assemblage, composed of *Nannoceratopsis gracilis* and *Phallocysta elongata*. Both species are well preserved (pale coloured), but some specimens of *N. gracilis* show slight damage due to crystal (pyrite?) growth. Rare, very well preserved specimens of *Deflandrea*, *Homotryblium*, *Polysphaeridium*, *Areoligera* and *Lejeunecysta* occur in this sample.

Ten samples from the lower part of the interval (729––850 m) yielded Palaeogene taxa. They are variously preserved: some show moderate preservation (yellow-brownish, relatively intact structure), but some forms are more poorly preserved, being darker coloured, commonly compressed and showing a high degree of alteration. Dinoflagellate cyst diversity varies from sample to sample. The topmost sample 729.1–734.0 m yielded small amounts of organic particles, predominantly black, opaque phytoclasts; rare

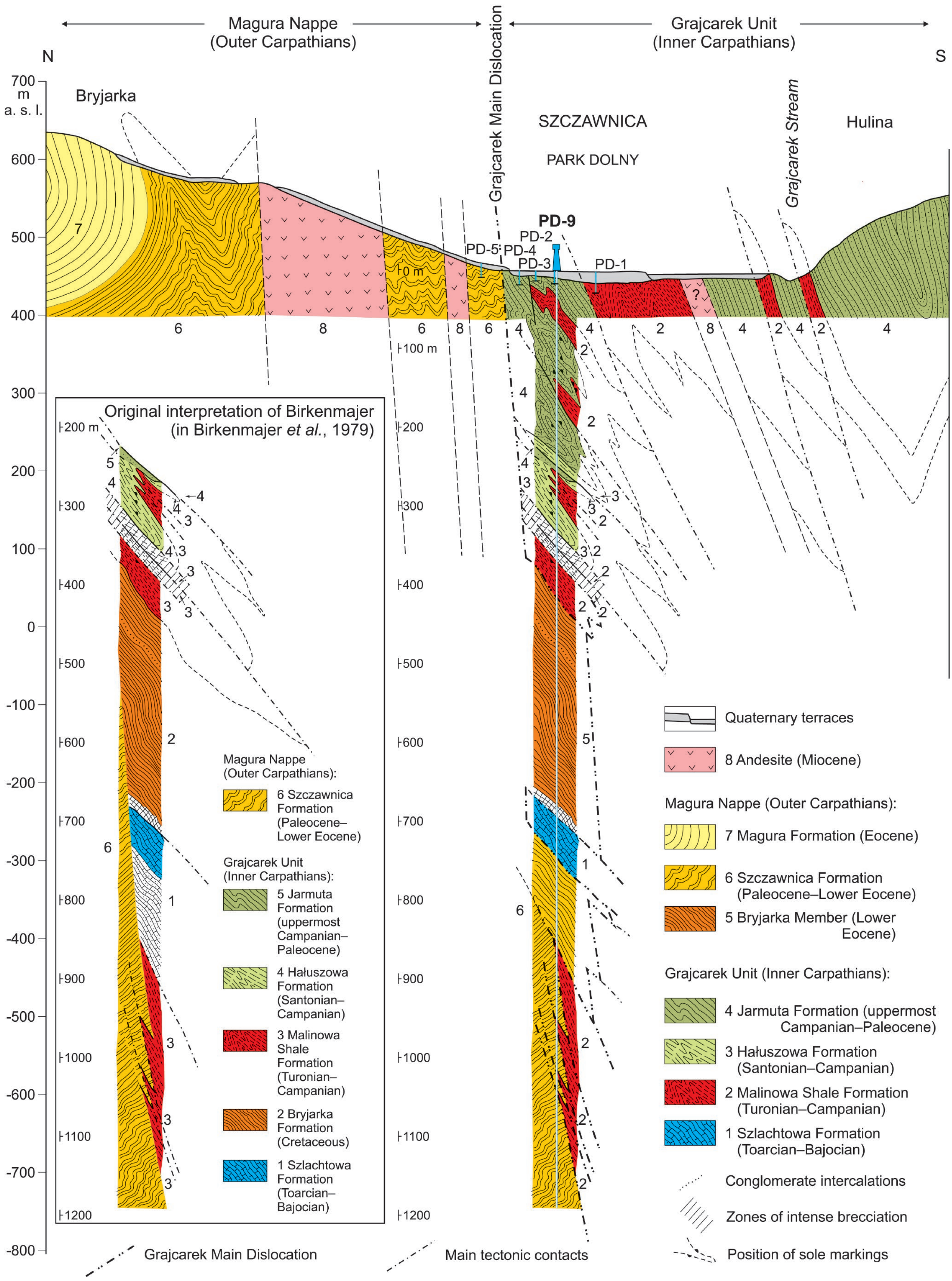


**Fig. 4.** Geological cross-section showing subsurface geological structure of the northern boundary fault zone of the Pieniny Klippen Belt at Szczawnica compared to its original interpretation (by K. Birkenmajer in Birkenmajer *et al.*, 1979).

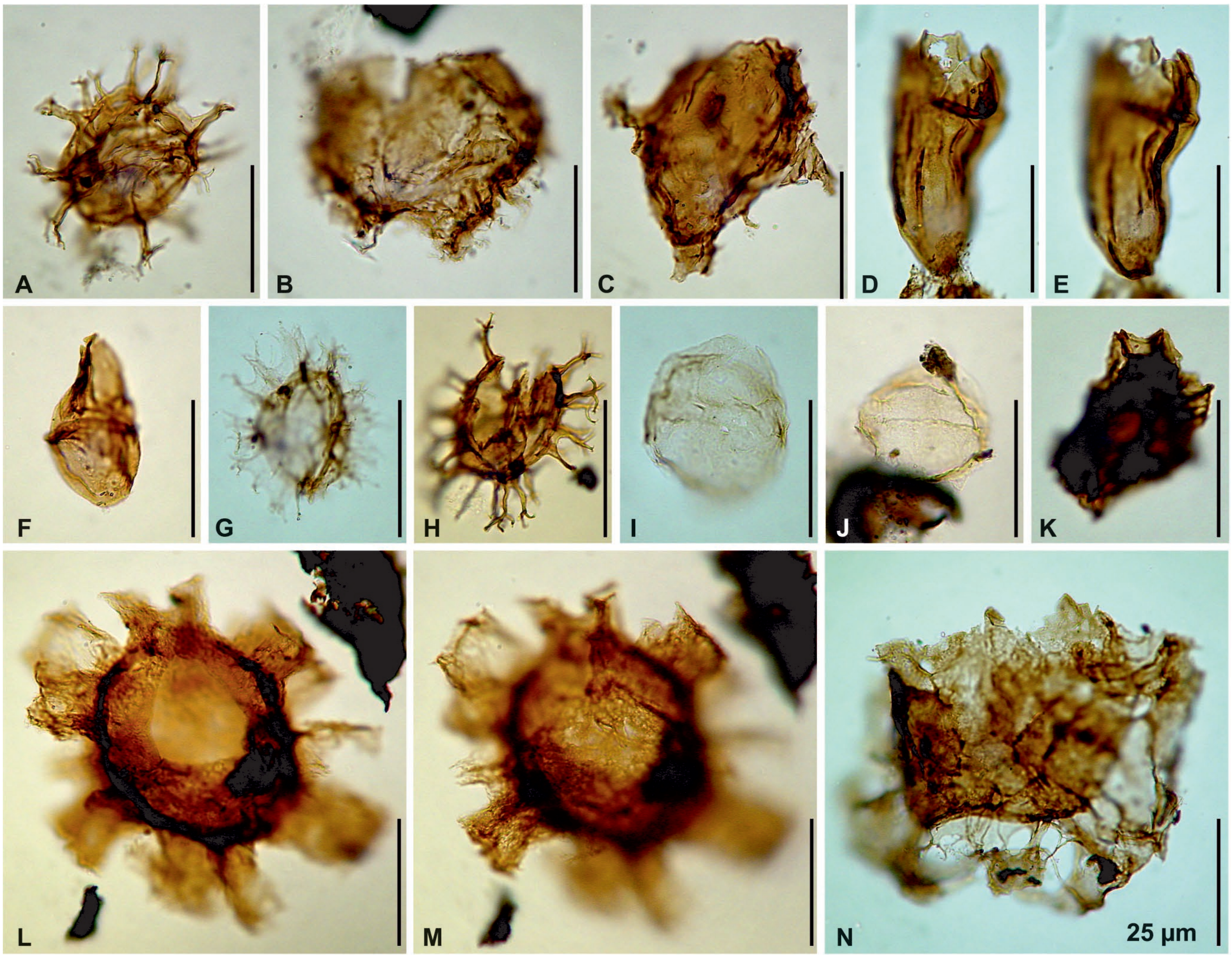


**Fig. 5.** Dinoflagellate cysts from the PD-9 borehole, the Hałuszowa Formation, uppermost Cretaceous (upper Senonian; photomicrographs by P. Gedl). Scale bar is 25 µm. **A.** *Spiniferites* sp. (285.8–289.8 m). **B.** *Circulodinium*? sp. (285.8–289.8 m). **C.** *Muderongia*? sp. (285.8–289.8 m). **D, E.** *Yolkinigymnium* sp. (same specimen, various foci; 292.7–297.8 m). **F.** *Dinogymnium* sp. (292.7–297.8 m). **G.** *Spiniferites* sp. (292.7–297.8 m). **H.** *Spiniferites* sp. (285.8–289.8 m). **I.** *Alterbidinium*? sp. (285.8–289.8 m). **J.** *Alterbidinium*? sp. (306.7–310.6 m). **K.** Poorly preserved *Pterodinium* sp. (266.7–270.6 m). **L, M.** *Cordosphaeridium fibrospinosum* (same specimen, various foci; 292.7–297.8 m). **N.** *Glaphyrocysta* sp. (292.7–297.8 m).

dinoflagellate cysts represented by a monospecific assemblage of *Areoligera* were found (*A. medusettiformis* complex; see chapter *Selected taxonomy*). *Areoligera* dominates (80%) also in the following sample from 738.4–744.3 m, associated with *Homotryblium tenuispinosum*, *Cordosphaeridium*, *Operculodinium*; this sample yielded large amounts of cuticles and palynodebris associated with frequent dinoflagellate cysts that constitute up to 10%.

The lower samples (765–850 m) contain rare and rather poorly preserved dinoflagellate cysts. They are dark brownish, commonly compressed and altered. The assemblages of them are dominated by gonyaulacoids; the peridinioids are mainly *Apectodinium* and other rare Wetzelielloideae.

Six samples representing the Szczawnica Formation (866–1006 m) yielded two different palynofacies. One of the samples from the lower part of this unit (below 924 m) consists of black, opaque phytoclasts (90–100%) and is generally without dinoflagellate cysts. The sample from a depth of 1002.4–1006.4 m yielded some pale coloured, well preserved palynomorphs that might be dinoflagellate cysts (*Batiacasphaera*? sp., *Rhiptocorys* sp. – no archaeopyle is visible). A single, darker coloured, poorly preserved specimen, questionably assigned to *Lingulodinium*, was found. As well, some fragments of presumably *Apectodinium* (in a similar state of preservation to the specimens in the sample from 866–869 m) were found. Other samples from this interval contain no dinoflagellate cysts; a single specimen of poorly preserved, dark brown *Alterbidinium*? sp. was found in sample 971.1–972.1 m.

The second palynofacies type occurs in the two uppermost samples from the Szczawnica Formation, at 920.0–924.6 m and 866–869 m. It is characterized by a higher proportion of dark brown phytoclasts (25–30%) that partly show preserved tissue structures, and by dinoflagellate cysts that represent 1–2% to 10%, respectively. Dinoflagellate cysts from both samples are brownish but relatively well preserved

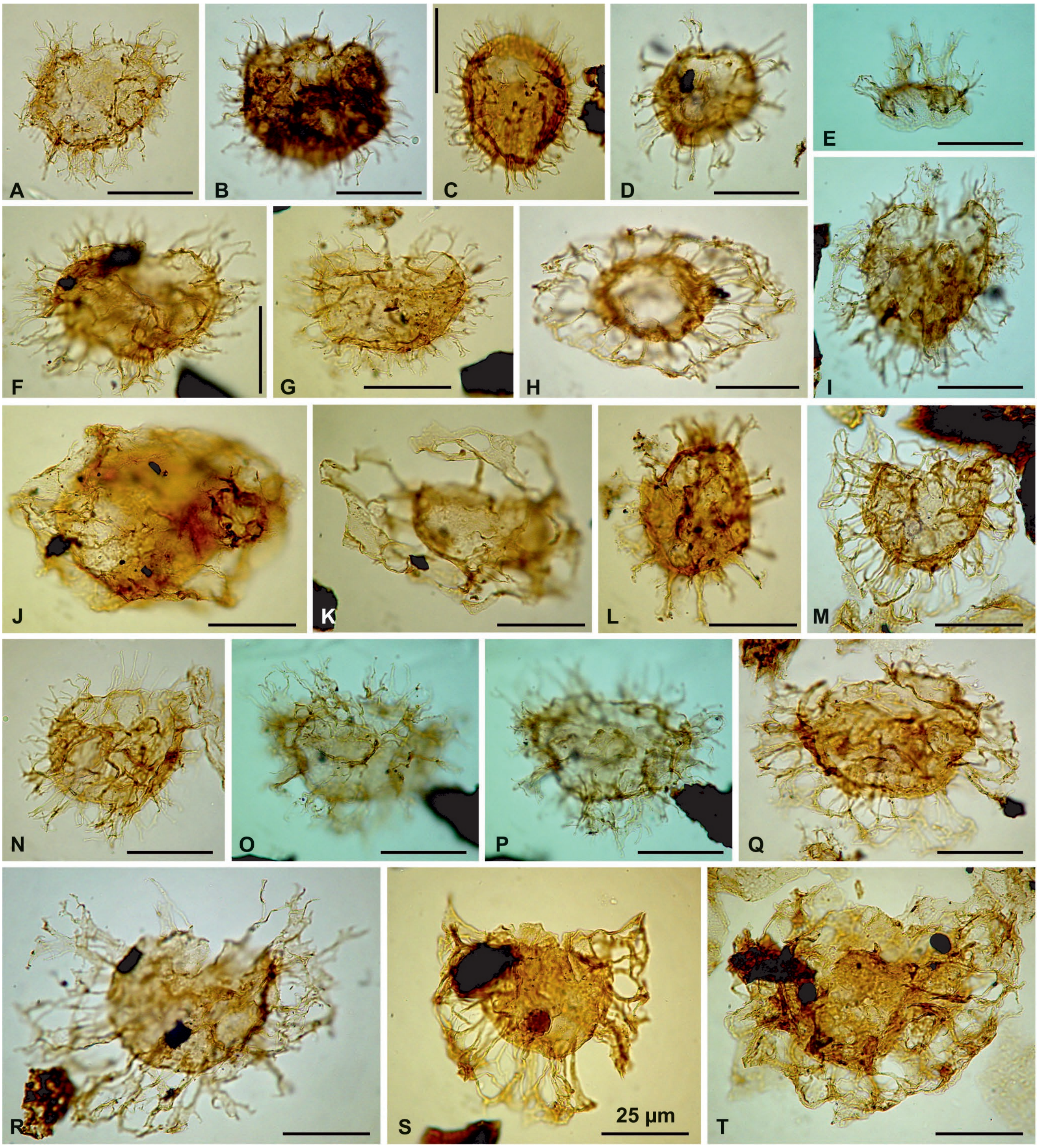
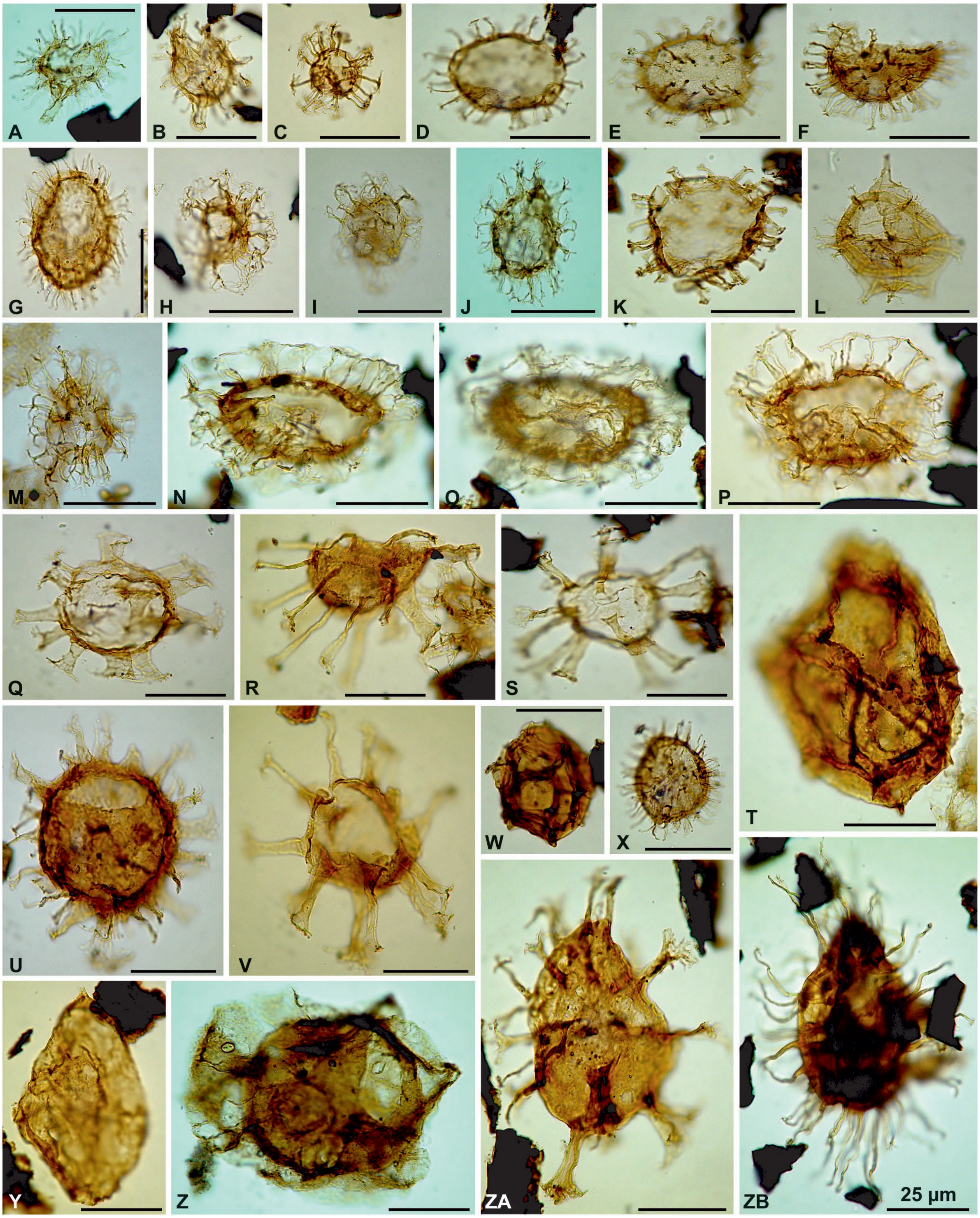


**Fig. 6.** Dinoflagellate cysts from the PD-9 borehole, the Bryjarka Member, Lower Eocene (photomicrographs by P. Gedl). Scale bar is 25 μm. **A.** *Areoligera medusettiformis* (662.3–668.8 m). **B.** *Areoligera medusettiformis* (631.0 m). **C.** *Operculodinium* sp. (569.8–575.1 m). **D.** *Systematophora* sp. (418.4–421.5 m). **E.** *Areoligera medusettiformis* – isolated operculum (662.3–668.8 m). **F.** *Areoligera medusettiformis* (505.1–509.7 m). **G.** *Areoligera medusettiformis* (505.1–509.7 m). **H.** *Adnatosphaeridium multispinosum* (691.8–696.6 m). **I.** *Areoligera medusettiformis* (505.1–509.7 m). **J.** *Thalassiphora patula* (635.5 m). **K.** *Adnatosphaeridium vittatum* (569.8–575.1 m). **L.** *Operculodinium divergens* (505.1–509.7 m). **M.** *Adnatosphaeridium multispinosum* (469.5–473.1 m). **N.** *Areoligera medusettiformis* (469.5–473.1 m). **O, P.** *Areoligera medusettiformis* (same specimen, various foci; 569.8–575.1 m). **Q.** *Glaphyrocysta* sp. (691.8–696.6 m). **R.** *Glaphyrocysta* sp. (638.1 m). **S.** *Glaphyrocysta exuberans* (469.5–473.1 m). **T.** *Glaphyrocysta spineta* (469.5–473.1 m).

**Fig. 7.** Dinoflagellate cysts from the PD-9 borehole, the Bryjarka Member, Lower Eocene (photomicrographs by P. Gedl). Scale bar is 25 μm. **A.** *Diphyes colligerum* (662.3–668.8 m). **B.** *Diphyes colligerum* (467.8–469.5 m). **C.** *Melitasphaeridium pseudorecurvatum* (653.1 m). **D, E.** *Polysphaeridium zoharyi* (same specimen, various foci: D – focus on archaeopyle margin; E – focus showing wall struc-



ture details; 653.1 m). **F.** *Polysphaeridium subtile* (653.1 m). **G.** *Operculodinium* sp. (691.8–696.6 m). **H.** *Nematosphaeropsis reticulensis* (691.8–696.6 m). **I.** *Nematosphaeropsis reticulensis* (569.8–575.1 m). **J.** *Spiniferites* sp. (662.3–668.8 m). **K.** *Polysphaeridium zoharyi* (653.1 m). **L.** *Rottnestia borussica* (569.8–575.1 m). **M.** *Spiniferites* sp. (469.5–473.1 m). **N, O.** *Adnatosphaeridium* cf. *multispinosum* (same specimen, various foci; 418.4–421.5 m). **P.** *Adnatosphaeridium* cf. *multispinosum* (418.4–421.5 m). **Q.** *Homotryblium abbreviatum* (691.8–696.6 m). **R.** *Homotryblium tenuispinosum* (569.8–575.1 m). **S.** *Homotryblium pallidum* (467.8–469.5 m). **T.** *Ynezidinium brevisulcatum* (540.2–544.5 m). **U.** *Operculodinium divergens* (569.8–575.1 m). **V.** *Homotryblium tenuispinosum* (505.1–509.7 m). **W.** *Impagidinium* sp. (653.1 m). **X.** *Operculodinium* sp. (653.1 m). **Y.** *Apteodinium* sp. (505.1–509.7 m). **Z.** *Thalassiphora patula* (631.0 m). **ZA.** *Cordosphaeridium inodes* (653.1 m). **ZB.** *Operculodinium microtriainum* (418.4–421.5 m).

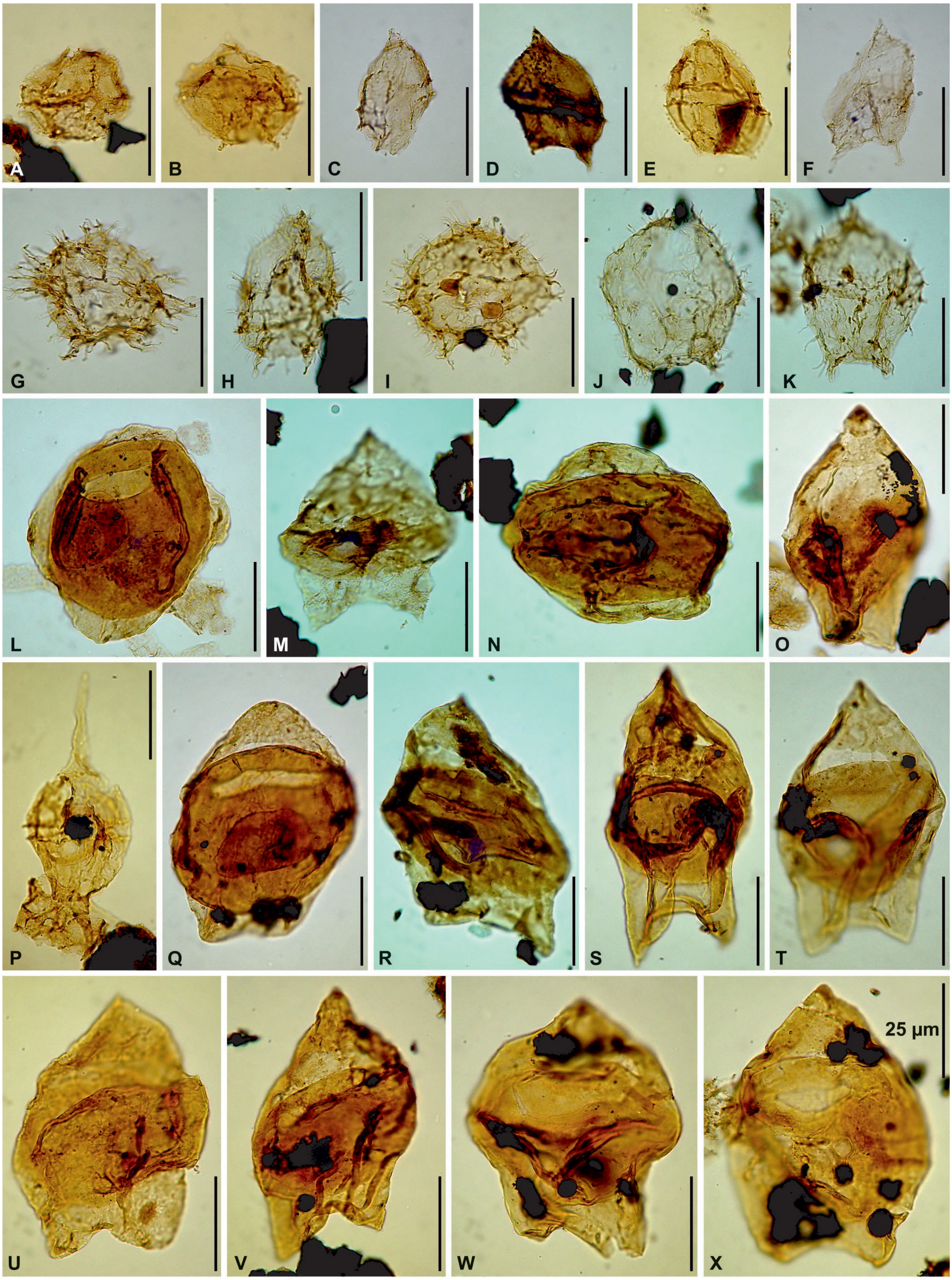


**Fig. 8.** Dinoflagellate cysts from the PD-9 borehole, the Bryjarka Member, Lower Eocene (photomicrographs by P. Gedl). Scale bar is 25 µm. **A.** *Phthanoperidinium delicatum* (635.5 m). **B.** *Phthanoperidinium delicatum* (569.8–575.1 m). **C.** *Phthanoperidinium* sp. (569.8–575.1 m). **D.** *Spinidinium* sp. (540.2–544.5 m). **E.** *Phthanoperidinium delicatum* (469.5–473.1 m). **F.** *Senegalinium*? sp. (569.8–575.1 m).

(Fig. 11). The most frequent in lower sample are *Areoligera* spp. and *Apectodinium homomorphum*. The most frequent in upper sample are *Areoligera* spp., *Spiniferites* spp., and *Homotryblium tenuispinosum*; rare Wetzelielloideae are dark brown (related to thicker walls). There are rare specimens of *Palaeohystrichophora infusorioides*, distinguished by very good preservation and pale colouration.

## BRYJARKA MEMBER

The Bryjarka Member (in the rank of formation) was described formally by Birkenmajer *et al*. (1979). The reason of distinguishing these flysch strata as a separate lithostratigraphic unit was their Cretaceous age, indicated on the basis of calcareous nannoplankton (Dudziak in Birkenmajer *et al*., 1979), which made such a rock body unique in the Pieniny Klippen Belt and the Magura Nappe of the Polish Carpathians. The age re-interpretation of the present authors makes the Bryjarka Member an age-equivalent of the Szczawnica Formation (*sensu* Birkenmajer and Oszczypko, 1989; see also Birkenmajer, 1960, 1965). Its characteristics are presented briefly below, following the account by Birkenmajer (in Birkenmajer *et al*., 1979), except for the elements re-interpreted.

**Name:** After Bryjarka Mount at Szczawnica.

**Type locality:** Szczawnica, borehole PD-9, interval of the core 415.00 to 702.50 m (45 m a.s.l to 242.5 m b.s.l).

**Thickness:** Incomplete, as both bottom and top contacts are tectonic, ca 190 m.

**Dominant lithology:** “Flysch deposits, predominantly sandstones and siltstones, usually calcareous (sometimes glauconitic), light to dark-grey and greenish, in layers usually 10–50 cm, sometimes up to 1–3 m thick. Alternating with argillaceous or feebly calcareous shales grey or grey-green, sometimes brownish or black (in the upper part of the member), 1–20, sometimes up to 80 cm thick. The ratio of sandstone to shale is usually 2:1. Mica flakes and carbonized plant detritus, sometimes accumulating in thin allochthonous black coal laminae occur here and there. Shale intraclasts and slump structures are rather frequent in the sandstones. A 3-m thick pebbly mudstone intercalation has been found in higher part of the unit” (from Birkenmajer *et al*., 1979).

**Boundaries:** Both boundaries are tectonic. The lower boundary with the Jurassic Szlachtowa Formation (the Grajcarek Unit); the units are separated by a brecciated zone, 2–3 m thick. The upper boundary with the Malinowa Shale Formation (the Grajcarek Unit), above which another brecciated zone occurs (Fig. 4).

**Age:** Lower Eocene, based on dinoflagellate cysts (Figs 6–9).

**Distribution:** The member is known from its type locality only.

**Equivalents:** The Bryjarka Member is coeval with the upper part of the Szczawnica Formation. It resembles lithologically the flysch facies (informal Kluszkowce Member; Birkenmajer, 1979) of the Szczawnica Formation; some other members of the latter, e.g., the Złatne Member, show different lithological features (see Birkenmajer and Oszczypko, 1989). The Bryjarka Member differs in the occurrence of intercalations of relatively pale, greenish shales, which in the case of the Szczawnica Formation are usually darker. Shales of similar colour occur in the Podmagurskie (Submagura) Beds (Birkenmajer, 1979).

## AGE INTERPRETATION OF DINOFLAGELLATE CYST ASSEMBLAGES

The lack of dinoflagellate cysts in the Jarmuta and Malinowa Shale formations from the PD-9 borehole does not allow age dating of them.

**Hałuszowa Formation.** Infrequent and poorly preserved specimens from the upper thrust sheet of the Hałuszowa Formation (Table 1; Fig. 5K) do not allow precise dating of this lithostratigraphic unit. The presence of pale-coloured *Dinogymnium* (early middle Turonian–latest Maastrichtian in mid-latitudes of the northern Hemisphere; Williams *et al*., 2004) and *Yolkinigymnium* sp. (known predominantly from upper Campanian–lower Maastrichtian strata; May, 1977; Lentin and Vozzhennikova, 1990) in the sample from a depth of 292.7 m indicates its uppermost Cretaceous age. This interpretation may be supported by the presence of *Cordosphaeridium fibrospinosum*, which although typically known from Palaeogene strata, appeared for the first time in the latest Cretaceous (Maastrichtian, according to e.g., Bujak and Williams, 1978; Williams *et al*., 1993; Stover *et al*., 1996; Oboh-Ikuenobe *et al*., 1998; but late Campanian according to May, 1980). Thus, an upper Campanian–lower Maastrichtian age can be suggested for the lower thrust sheet of the Hałuszowa Formation in the PD-9 borehole.

**Bryjarka Member.** Rich and relatively diversified dinoflagellate cyst assemblages from the Bryjarka Member show that this unit is Lower Eocene (Ypresian); this age is based on the following species.

Representatives of the genus *Apectodinium* (*A. homomorphum*, *A. hyperacanthum*, *A. augustum*, *A. paniculatum*, *A. parvum*, *A. quinquelatum*, and *A. summissum*) appeared for the first time in the latest Thanetian (NP9 Zone; Powell, 1992); they range to: the Paleocene-Eocene boundary (*A. augustum*), earliest Ypresian (*A. hyperacanthum*, *A. summissum*; dinocyst D5b Zone), early Ypresian (*A. parvum*; NP10, D6b zones; *A. paniculatum*, NP11, D6b), late Ypresian (*A. quinquelatum*; NP13, D8 zones). In the present material, *Apectodinium parvum* occurs in

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**G.** *Apectodinium homomorphum* (642.6 m). **H.** *Apectodinium parvum* (426.3–431.1 m). **I.** *Apectodinium summissum* (426.3–431.1 m). **J.** *Apectodinium parvum* (418.4–421.5 m). **K.** *Apectodinium parvum* (418.4–421.5 m). **L.** *Dracodinium laszczynskii* (469.5–473.1 m). **M.** *Deflandrea* sp. (625.7 m). **N.** *Deflandrea eocenica* (625.7 m). **O.** *Isabelidinium*? sp. (505.1–509.7 m). **P.** *Biconidinium longissimum* (469.5–473.1 m). **Q.** *Deflandrea leptodermata* (569.8–575.1 m). **R–T.** *Isabelidinium*? sp. (R: 625.7 m; S, T: 653.1 m). **U–X.** *Deflandrea* sp. (U–X: 505.1–509.7 m).

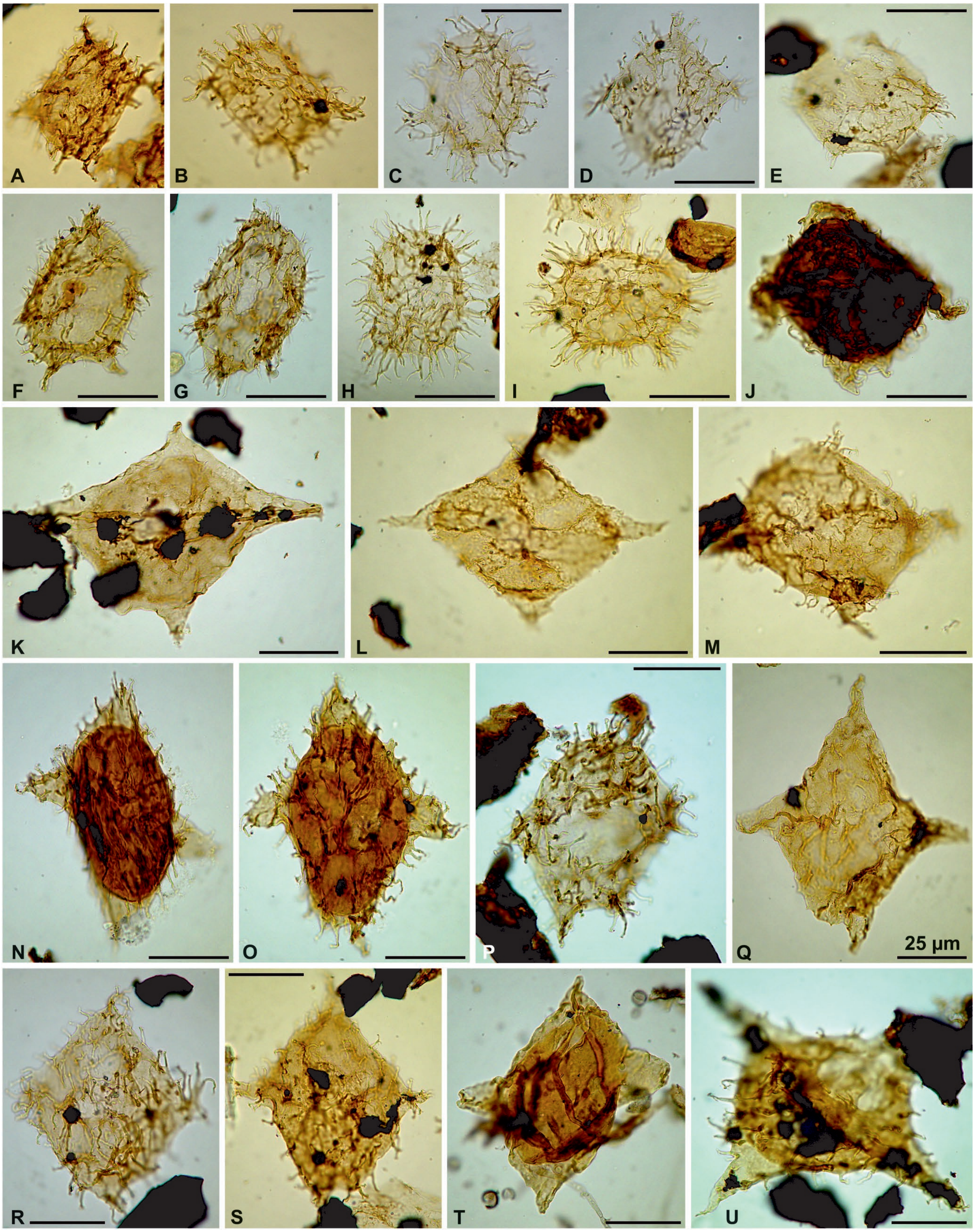

**Fig. 9.** Dinoflagellate cysts from the PD-9 borehole, the Bryjarka Member, Lower Eocene (photomicrographs by P. Gedl). Scale bar is 25 µm. **A.** *Wetzeliella astra* (505.1–509.7 m). **B.** *Wetzeliella astra* (569.8–575.1 m). **C.** *Apectodinium homomorphum* (569.8–575.1 m). **D.** *Apectodinium quinquelatum* (569.8–575.1 m). **E.** *Apectodinium summissum* (418.4–421.5 m). **F.** *Apectodinium parvum* (426.3–431.1 m). **G.** *Apectodinium parvum* (431.1–436.5 m). **H.** *Apectodinium homomorphum* (469.5–473.1 m). **I.** *Apectodinium homomorphum* (569.8––575.1 m). **J.** *Wetzeliella* sp. (653.1 m). **K.** *Wetzeliella unicaudalis* (642.6 m). **L.** *Rhombodinium* cf. *longimanum* (569.8–575.1 m). **M.** *Wetzeliella* sp. (569.8–575.1 m). **N.** *Wetzeliella* sp. (631.0 m). **O.** *Wetzeliella* sp. (540.2–544.5 m). **P.** *Wetzeliella astra* (505.1–509.7 m).

the three topmost samples (interval 431.1–418.4 m), *A. summissum* occurs in two of the topmost samples (418.4––421.5 m and 426.3–431.1 m), and *A. quinquelatum* occurs in samples 426.3–431.1 m and 569.8–575.1 m.

*Wetzeliella unicaudalis*, found in samples from the basal depths of 662.3–668.8 m and 642.6 m, was described by Caro (1973) from the Lower Eocene of the Pyrenees. *Biconidinium longissimum* found in the sample from the depth of 469.5–473.1 m was described from Lower Eocene of southern England (Islam, 1983). According to Williams *et al.* (2004), the stratigraphic range of *B. longissimum* is limited to the early (but not earliest)–middle Ypresian. *Wetzeliella meckelfeldensis* is another species, the age-range of which is limited to the Ypresian (middle–late Ypresian; Williams and Bujak, 1985; Williams *et al*., 2004). *Wetzeliella astra* has an older age range of early Ypresian (NP10, base of the D6a–of D6b zones; Powell, 1992).

The southern Hemisphere species *Dracodinium waipawaense* found in sample 431.1–436.5 m has an age-range limited to the middle Ypresian (Williams *et al*., 2004). Beside *D. waipawense*, some other species of *Dracodinium* are either mid Ypresian species (*D. simile*, *D. solidum*, and *D. condylos*) or they appeared for the first time in the mid Ypresian and range to the Lutetian (*D. pachydermum*, *D. varielongitudum*, and *D. politum*). The presence of *Dracodinium laszczynskii* in the Bryjarka Member indicates that this species, so far considered to be Bartonian, has a wider age-range, including also mid?–late Ypresian, or the previous dating of it was erroneous (see chapter *Comparison…*).

*Melitasphaeridium pseudorecurvatum* and *Deflandrea phosphoritica*, both found in the Bryjarka Member, are known to have appeared for the first time in mid-latitudes of the northern Hemisphere during the early Ypresian (Williams *et al*., 2004). Also *Homotryblium tenuispinosum*, which is widespread in the present material, appeared for the first time in the late Paleocene (Thanetian; Williams *et al.,* 2004) and earliest Eocene, according to Williams and Bujak (1985). Similarly, *Polysphaeridium zoharyi*, which occurs in most of the samples studied from this lithostratigraphic unit, appeared for the first time in the early Eocene (Bujak and Williams, 1979). *Adnatosphaeridium vittatum*, which occurs in the topmost sample (418.4–421.5 m) and in the sample from a depth of 569.8–575.1 m, appeared for the first time in the mid Ypresian (NP12, D8 zones) and ranged to the Lutetian/Bartonian (NP16, D10 zones; Powell, 1992).

More precise dating is difficult, owing to possible tectonic disturbances and taxonomically impoverished assemblages in some samples. Although Birkenmajer *et al.* (1979) demonstrated the generally homogenous dip of strata making up the Bryjarka Member (Fig. 4), the precise orientation of the top and bottom was not stated and some minor, tectonic disturbances cannot be excluded. These facts all indicate that superposition cannot be used as an additional criterion for dating. Below, the ages of particular samples of the Bryjarka Member (in descending order; Table 1) are suggested.

The two uppermost samples (418.4–421.5 m and 426.3–431.1 m) most likely represent the lowermost Ypresian (the presence of *A. summissum*), although the presence of *W. meckelfeldensis* (middle–upper Ypresian; Williams and Bujak, 1985) and *Adnatosphaeridium multispinosum* (lowest occurrence in mid Ypresian; Stover *et al*., 1996) indicate a slightly younger age.

A lower sample (431.1–436.5 m) is lower Ypresian (the presence of *A. parvum*). The sample from a depth of 467.8–469.5 m can be dated as middle–upper Ypresian, owing to the presence of *W. meckenfeldensis*. The following lower sample (469.5–473.1 m) may be slightly older or coeval: lower (but not lowermost)–middle Ypresian (range of *B. longissimum*; Williams *et al*., 2004). A lower Ypresian age can be suggested for samples from 505.1–509.7 m (the co-occurrence of *Deflandrea oebisfeldensis*: the highest occurrence in lower Ypresian: Williams *et al*., 2004, and *Wetzeliella astra*: lower Ypresian, NP10, D6a–base of D6b: Powell, 1992) and 540.2–544.5 m (the presence of *D. oebisfeldensis*; an older, uppermost Paleocene age of this sample cannot be excluded, owing to the lack of other Ypresian species).

The presence of *A. quinquelatum* (the highest occurrence in the upper Ypresian) in the sample from a depth of 569.8–575.1 m indicates a generally Ypresian age.

Lower samples yielded impoverished assemblages with very rare good age indicators making their dating imprecise. Sample 584.3–589.1 m yielded *A. homomorphum* (highest occurrence in Bartonian; Stover *et al.,* 1996). Samples 604––606 m and 625.7 m yielded *Delflandrea eocenica* (Ypresian; Balteş, 1969). A mid Ypresian age of samples 631.0 m and 635.5 can be indicated by the presence of *Thalassiphora patula* (Stover *et al.,* 1996). A lower sample (638.1 m) yielded the long-ranging *H. tenuispinosum* and *P. zoharyi*. *W. unicaudalis* (Ypresian; Caro, 1973) occurs in sample 642.6 m. Sample 653.1 m yielded *Dracodinium laszczynskii*, described from the Bartonian of the Magura Nappe (see chapter *Comparison…*). Lower–mid Ypresian can be indicated for sample 662.3–668.8 m on the basis of the co-occurrence of *W. unicaudalis* (Ypresian) and *Glaphyrocysta ordinata* (Thanetian–mid Ypresian; Stover *et al*., 1996). The lowermost sample from the Bryjarka Member yielded *A. multispinosum* (the lowest occurrence in the mid Ypresian; Stover *et al.,* 1996).

Another indication of the Ypresian, most likely mid-Ypresian age of the Bryjarka Member is the frequent occurrence of the *Areoligera medusettiformis* complex (see chapter *Taxonomy of selected dinoflagellate cysts*). Several acmes of these species are known from the Ypresian of the North Sea (Gradstein *et al.,* 1992; Bujak and Mudge, 1994; Mudge and Bujak, 1996a, b; see King, 2016, for overview, correlation and unpublished data).

The age interpretation presented above shows that the Bryjarka Member represents the lower–middle Ypresian. The oldest samples – lower Ypresian – are in the upper part

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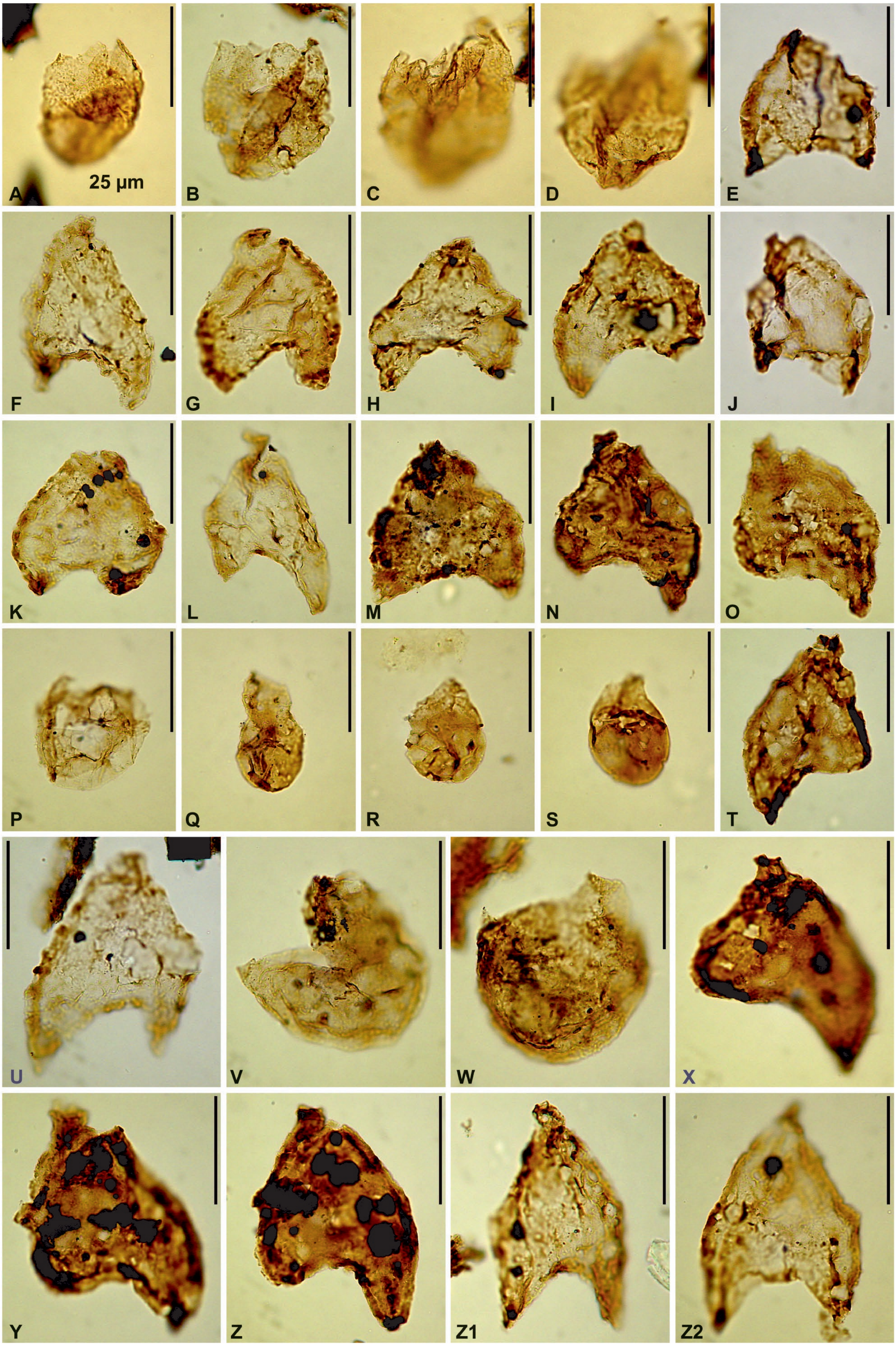
**Q.** *Rhombodinium* sp. A (426.3–431.1 m). **R.** *Wetzeliella* sp. (569.8–575.1 m). **S.** *Wetzeliella* sp. (569.8–575.1 m). **T.** *Dracodinium waipawense* (431.1–436.5 m). **U.** *Wetzeliella meckelfeldensis* (418.4–421.5 m).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of the interval cored. This may indicate that this unit is in upside-down position.

The lowermost Ypresian and the Paleocene-Eocene boundary interval are not present in the material studied. These intervals are known for the Paleocene-Eocene Thermal Maximum and they are characterized by the very frequent occurrence of warm-water *Apectodinium* species (e.g., Bujak and Brinkhuis, 1998; Crouch *et al.,* 2001). This genus, although present in the material studied, never forms acmes there.

**Szlachtowa Formation.** Two samples representing the Jurassic Szlachtowa Formation yielded various dinocyst assemblages. The low taxonomic diversity in the lower sample, 710.4–716.4 m, makes its dating highly imprecise.

The presence of *Nannoceratopsis dictyambonis* and poorly preserved *Dissiliodinium* specimens (but not *D. giganteum*) in the upper sample (707.1–710.4 m) indicates its upper upper Aalenian age. The stratigraphic range of *N. dictyambonis* is Aalenian–earliest Bajocian (Prauss, 1989), latest Toarcian–early Bajocian (Stover *et al.,* 1996), and late Toarcian–early Bajocian (Bucefalo Palliani and Riding, 1997). The oldest record of *Dissiliodinium* goes back to the upper upper Aalenian, namely the upper part of the *Ludwigia murchisonae* Zone (Feist-Burkhardt, 1990) and the *Graphoceras concavum* Zone (Feist-Burkhardt and Wille 1992; Feist-Burkhardt and Pross, 2010). The sample studied yielded no *D. giganteum*, which has its lowest occurrence in the lowermost Bajocian (e.g., Feist-Burkhardt and Monteil, 2001). However, Wiggan *et al.* (2017) also reported this species from the uppermost Aalenian (*Graphoceras concavum* Zone) and Feist-Burkhardt (1990) from the uppermost *Graphoceras concavum* Zone. The lack of *D. giganteum*, which is a widespread species in the lower Bajocian of the Pieniny Klippen Belt (Gedl, 2008, 2013; Gedl and Józsa, 2015; Segit *et al.*, 2015) delimits the upper age-range of the sample discussed to uppermost Aalenian.

A slightly older age can be suggested for the Jurassic assemblage from the lower sample (710.4–716.4 m), which yielded rare specimens of two species, *Nannoceratopsis gracilis* and *Phallocysta elongata*. The latter species has its lowest occurrence in the upper Toarcian (Bucefallo Palliani and Riding, 1997); Feist-Burkhardt (1990) reported an Aalenian range of this species (the highest occurrence in the uppermost *Graphoceras concavum* Zone). The lack of *Dissiliodinium* excludes the upper upper Aalenian. Therefore, upper Toarcian–lower upper Aalenian can be suggested, but it should be noted that the scarcity of dinoflagellate cysts in this sample does not allow precise dating.

**Szczawnica Formation.** The core interval below (729.1––850.6 m), previously assigned to the Szlachtowa Formation, yielded Early Eocene dinoflagellate cyst assemblages, similar to those that occur in the Szczawnica Formation at the borehole base (the two uppermost samples: 866–869 m and 920–924.6 m), and in the Bryjarka Member (Table 1). The same Ypresian age can be suggested on the basis of the presence of such species such as, i.a., *Apectodinium homomorphum*, *A. quinquelatum*, *A. parvum*, *Homotryblium tenuispinosum*, *Polysphaeridium zoharyi* and *Thalassiphora patula* (see subchapter *Bryjarka Member* for detailed ranges and citations). The sample from a depth of 801.3–805.8 m yielded *Dracodinium condylos*, known from the upper Ypresian–lower Lutetian (Stover *et al.,* 1996) or from mid Ypresian exclusively (Williams *et al*., 2004). The Szczawnica Formation from the lowermost interval drilled (924.6––1006.4 m) yielded no dinoflagellate cysts or very rare, poorly preserved forms (1002.4–1006.4 m; Table 1). Among the latter, the Late Cretaceous *Rhiptocorys* sp. was identified. Its presence, if it was not recycled, together with the questionably determined *Alterbidinium*? sp. in sample 971.1––972.1 m, may indicate a Late Cretaceous age for this part of the Szczawnica Formation. The recycling or contamination (samples from the Szczawnica Formation are bailer samples) is evidenced by the presence of well-preserved Late Cretaceous *Palaeohystrichophora infusorioides* in sample 866–869 m that yielded much worse preserved Eocene assemblages.

## COMPARISON WITH DINOFLAGELLATE CYST ASSEMBLAGES FROM NEIGHBOURING AREAS

**Hałuszowa Formation.** Palynology of this lithostratigraphic unit was described by Gedl (2007) from exposures at Hałuszowa, Pieniny Klippen Belt. Two samples studied yielded small amounts of palynological organic matter, predominantly composed of black, small-sized, equidimensional, opaque phytoclasts; subordinate occurrences of highly degraded larger cuticles were noted. The same type of palynofacies was found in the present material. The similarity between these two sites does not refer to dinoflagellate cyst assemblages, which although equally infrequent, show significant taxonomical differences. The assemblages from Hałuszowa are dominated by the peridinioid *Subtilisphaera*-morphotype, associated with infrequent gonyaulacoids. In the PD-9 material, peridinioids are rare. These

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**Fig. 10.** Dinoflagellate cysts from the PD-9 borehole, the Szlachtowa Formation, Aalenian–Bajocian (photomicrographs by P. Gedl). Scale bar is 25 µm. **A.** *Batiacasphaera* sp. (707–710 m). **B.** *Batiacasphaera* sp. (707–710 m). **C, D.** *Kallosphaeridium praussii* (707–710 m). **E.** *Nannoceratopsis* sp. (707–710 m). **F.** *Nannoceratopsis dictyambonis* (707–710 m). **G.** *Nannoceratopsis dictyambonis* (707–710 m). **H.** *Nannoceratopsis* sp. (707–710 m). **I.** *Nannoceratopsis gracilis* (707–710 m). **J.** *Nannoceratopsis* sp. (707–710 m). **K.** *Nannoceratopsis dictyambonis* (707–710 m). **L.** *Nannoceratopsis gracilis* (707–710 m). **M.** *Nannoceratopsis raunsgaardii* (707–710 m). **N.** *Nannoceratopsis gracilis* (707–710 m). **O.** *Nannoceratopsis gracilis* (710–176 m). **P.** *Kallosphaeridium*? sp. (707–710 m). **Q.** *Phallocysta elongate* (710–176 m). **R.** *Phallocysta* sp. (710–176 m). **S.** *Phallocysta* sp. (710–176 m). **T.** *Nannoceratopsis gracilis* (710–176 m). **U.** *Nannoceratopsis dictyambonis* (707–710 m). **V.** *Dissiliodinium* sp. (707–710 m). **W.** *Kallosphaeridium*? sp. (707–710 m). **X.** *Nannoceratopsis gracilis* (707–710 m). **Y.** *Nannoceratopsis gracilis* (707–710 m). **Z.** *Nannoceratopsis gracilis* (707–710 m). **Z1.** *Nannoceratopsis spiculata* (707–710 m). **Z2.** *Nannoceratopsis spiculata* (707–710 m).

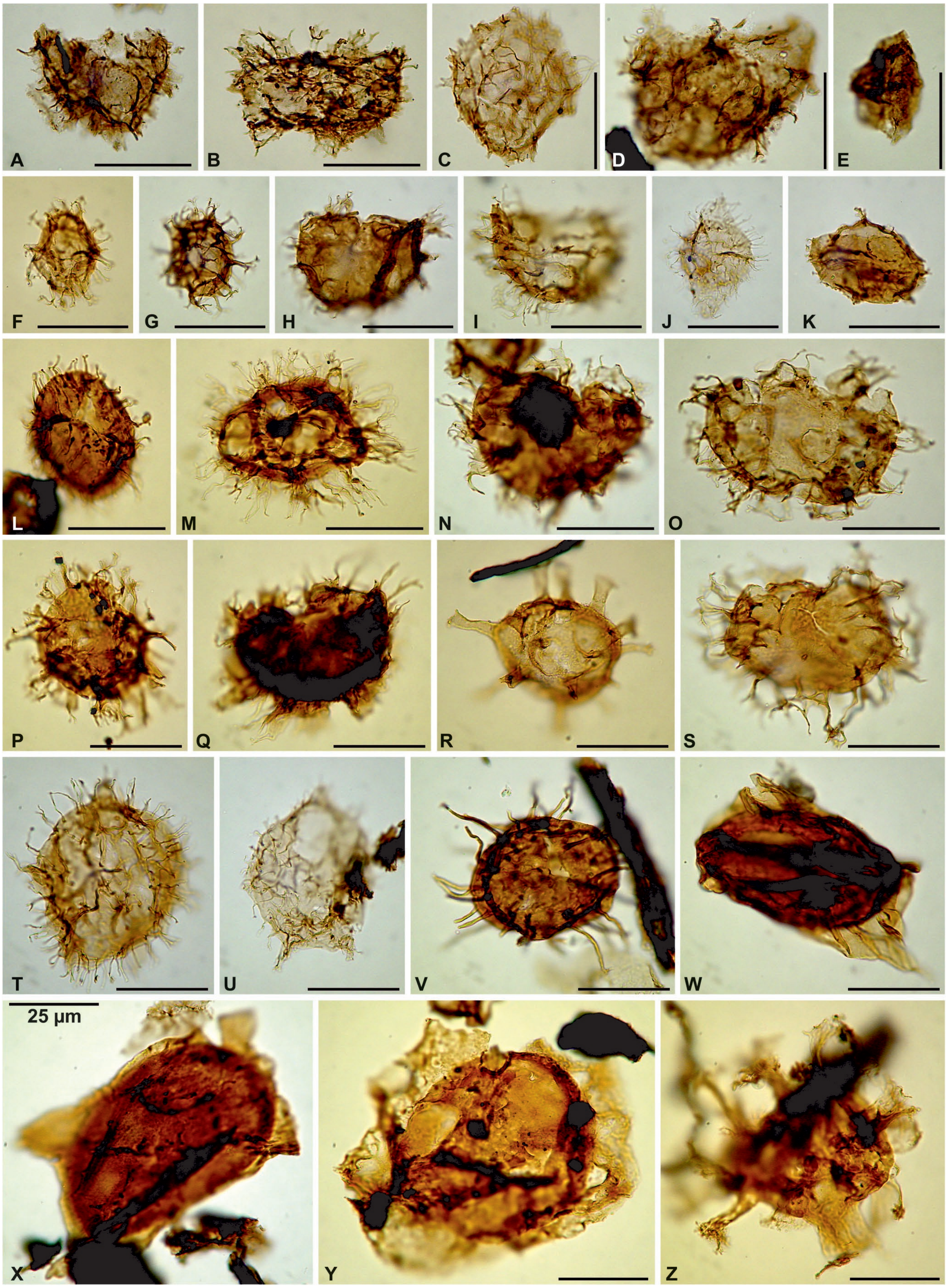

**Fig. 11.** Dinoflagellate cysts from the PD-9 borehole, the Szczawnica Formation, Lower Eocene (photomicrographs by P. Gedl). Scale bar is 25 µm. **A.** *Areoligera medusettiformis* (920–924 m). **B.** *Areoligera medusettiformis* (920–924 m). **C.** *Apectodinium* sp. (920–924 m). **D.** *Areoligera medusettiformis* (920–924 m). **E.** *Alterbidinium*? sp. (971–972 m). **F.** *Spiniferites* sp. (866–869 m). **G.** *Spiniferites* sp.

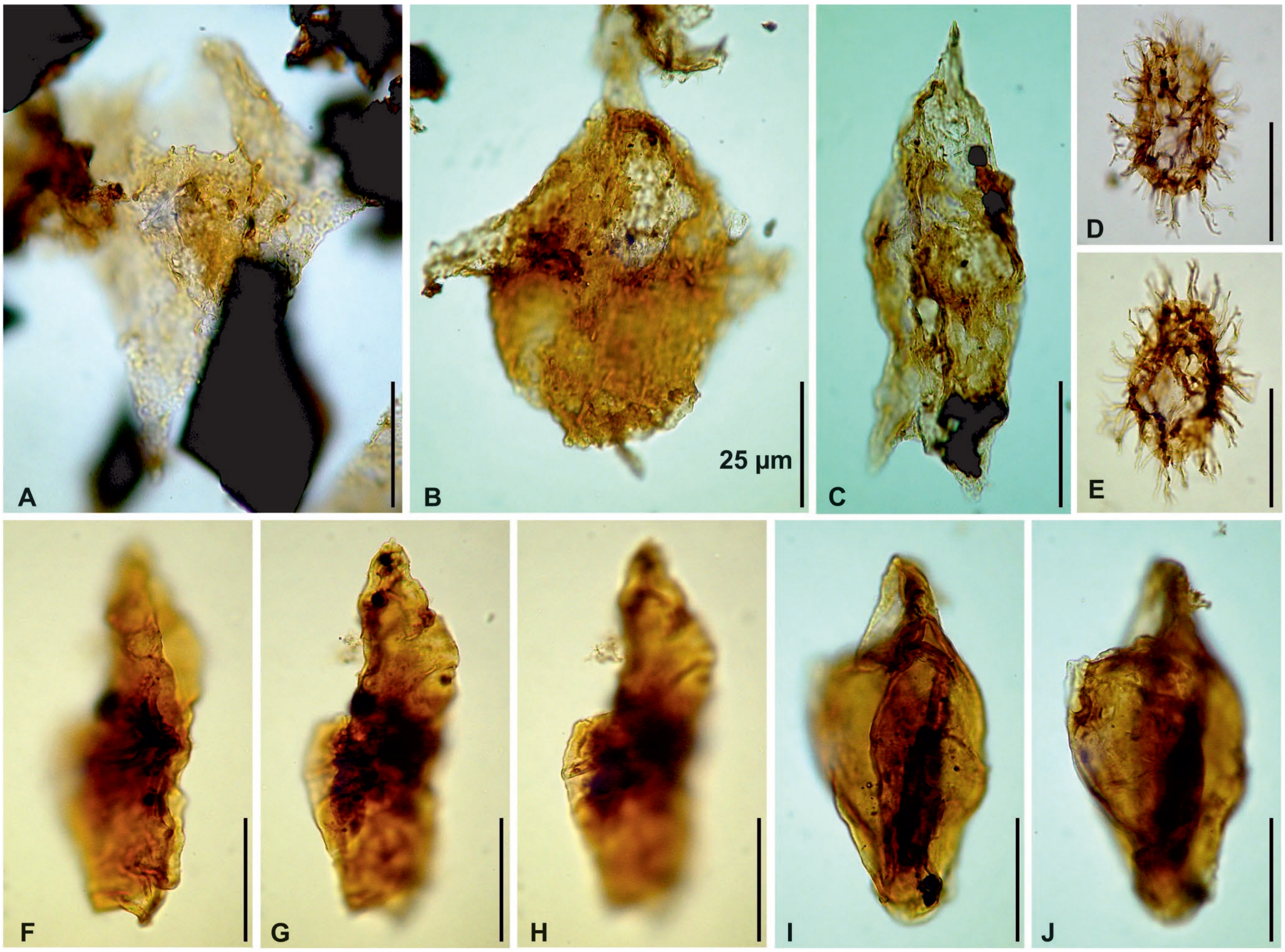

**Fig. 12.** Dinoflagellate cysts from the PD-9 borehole (photomicrographs by P. Gedl). Scale bar is 25 µm. **A.** *Rhombodinium*? sp. (418.4–421.5 m). **B.** *Rhombodinium*? sp. (505.1–509.7 m). **C.** *Deflandrea* sp. (625.7 m). **D.** *Apectodinium* cf. *homomorphum* (505.1–509.7 m). **E.** *Apectodinium* cf. *homomorphum* (505.1–509.7 m). **F–H.** *Deflandrea*? sp. (same specimen, various foci; 505.1–509.7 m). **I, J.** *Deflandrea*? sp. (same specimen, various foci; 505.1–509.7 m).

differences can be associated with variable, palaeoenvironmental conditions, either in time or space, during the accumulation of the flysch strata of the Hałuszowa Formation. The precise dating of dinoflagellate cyst assemblages is limited, owing to their scarcity: latest Albian–early Campanian, in the case of the Hałuszowa material (Gedl, 2007) and younger, late Campanian–early Maastrichtian, in the present material. But these differences may also reflect varying intensity of resedimentation of the proximal material into basin bottom during flysch sedimentation.

**Szczawnica Formation and Bryjarka Member.** Early Palaeogene dinoflagellate cysts from the Pieniny Klippen Belt and the adjacent part of the Magura Nappe have not yet been studied intensively.

Gedl (1995) described rich assemblages from the Eocene of the Magura Nappe, exposed at the tectonic contact between the Pieniny Klippen Belt and the Magura Nappe at Rogoźnik. These assemblages show some taxonomical similarities with the Bryjarka Member assemblages, including common species, some of which appeared for the first time in the Ypresian (Williams and Bujak, 1985; Stover *et al.,* 1996; Williams *et al.,* 2004), i.a., *Adnatosphaeridium multispinosum*, *A. vittatum*, *Apectodinium homomorphum*, *A. quinquelatum*, *A. summissum*, *Areoligera coronata*, *A. medusettiformis*, *Cordosphaeridium inodes*, *Dracodinium laszczynskii*, *Glaphyrocysta exuberans*, *G. laciniiforme*, *G. ordinata*, *Homotryblium abbreviatum*, *H. caliculum*, *H. pallidum*, *H. tenuispinosum*, *Melitasphaeridium pseu-*

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(866–869 m). **H.** *Areoligera medusettiformis* (866–869 m). **I.** *Areoligera medusettiformis* (866–869 m). **J.** *Palaeohystrichophora infusorioides* (866–869 m). **K.** *Phthanoperidinium delicatum* (866–869 m). **L.** *Operculodinium* sp. (866–869 m). **M–Q.** *Areoligera medusettiformis* (866–869 m). **R.** *Homotryblium tenuispinosum* (866–869 m). **S.** *Areoligera medusettiformis* (866–869 m). **T.** *Apectodinium homomorphum* (866–869 m). **U.** *Apectodinium parvum* (866–869 m). **V.** *Operculodinium microtriainum* (866–869 m). **W.** *Rhombodinium* sp. (866–869 m). **X.** *Wilsonidium intermedium* (866–869 m). **Y.** *Thalassiphora* sp. (866–869 m). **Z.** *Cordosphaeridium fibrospinosum* (866–869 m).

*dorecurvatum*, *Nematosphaeropsis reticulensis*, *Rottnestia borussica*, and *Wetzeliella unicaudalis*. Gedl (1995) suggested a Middle Eocene (NP16) age for the Rogoźnik assemblages on the basis of the occurrence of *Rhombodinium draco* (which is absent in the Bryjarka assemblages), and interpreted the older species as being reworked. However, the *R. draco* specimens from Rogoźnik show some similarities with PD-9 specimen determined as *Dracodinium waipawaense* from the present material. This could indicate that the Rogoźnik assemblages are older than was previously suggested, Early–early Middle Eocene (Ypresian–Lutetian), approximately coeval with the Bryjarka assemblages. *Wetzeliella meckelfeldensis* (Ypresian; Williams and Bujak, 1985) occurs in the Bryjarka Member; a species determined as *W*. sp. cf. *W. meckelfeldensis* was found in the Rogoźnik assemblages. The Rogoźnik assemblages include *Charlesdowniea coleothrypta* (absent in the Bryjarka Member), that goes back to mid Ypresian (Williams and Bujak, 1985; Stover *et al.,* 1996; Williams *et al.,* 2004). The lack of this species in the Bryjarka Member may indicate that it is slightly older than the Eocene Rogoźnik strata.

More recently, Segit (in Jurewicz and Segit, 2018) described a latest Paleocene?–early Eocene assemblage from a single sample from near Szczawnica (Czarna Woda Creek; for the lithostratigraphic affiliation of the sample studied, see p. 138). It is dominated by *Glaphyrocysta*, *Areoligera*, *Apectodinium homomorphum* and *Cleistosphaeridium diversispinosum* and includes some age-diagnostic species in common with the Bryjarka Member, i.a., *Apectodinium homomorphum*, *A. quinquelatum*, and *Glaphyrocysta ordinata*. Their co-occurrences show that at least a part of the Bryjarka Member may be coeval with the sample from the Czarna Woda Creek.

A possibly coeval dinoflagellate cyst assemblage was reported by Gedl (2000) from a single sample from an exotic-bearing layer of the Fore-Dukla Zone, the Silesian Nappe, Flysch Carpathians (for details see Bąk *et al.,* 2001). It included, i.a., *Wetzeliella unicaudalis*, which indicates its Early Eocene age (Caro, 1973).

**Szlachtowa Formation.** Jurassic dinoflagellate cysts from the Szlachtowa Formation, Pieniny Klippen Belt, were extensively studied in recent years (e.g., Gedl, 2008, 2013; Barski *et al.,* 2012; Gedl and Józsa, 2015; Segit *et al.,* 2015). Their ages, depending on the author and the succession studied (for details see Birkenmajer *et al.,* 2008; Gedl *et al.,* 2012; Jurewicz and Segit, 2018) span the late Early to Middle Jurassic or exclusively the Middle Jurassic. The assemblage with frequent *Nannoceratopsis dictyambonis*, associated with *Nannoceratopsis* spp. and *Dissiliodinium* sp. from the upper sample of the Szlachtowa Formation, most likely can be correlated with the upper Aalenian *Dissiliodinium lichenoides* Zone, Pieniny Klippen Belt, southern Poland (Gedl, 2008), although the index species was not determined. A very similar assemblage was described from a single sample, CzS4, from the Czerwona Skała site (Skrzypny Shale Formation; Gedl, 2008, p. 159), which was dated to upper Bajocian, owing to the determination of *N. pellucida*, which might have been erroneous.

The taxonomically impoverished assemblage with *N. gracilis* and *Phallocysta elongata* does not allow precise correlation with the other assemblages described from the Pieniny Klippen Belt, but the presence of *Phallocysta elongata* and the lack of younger species, may indicate its correlation with upper Toarcian and lower–middle Aalenian *Phallocysta elongata* and *Nannoceratopsis evae* zones (Gedl, 2008).

Segit *et al*. (2015) described from the upper Aalenian–lowermost Bajocian of the Sprzycne Creek, Pieniny Klippen Belt, dinoflagellate cyst assemblages with *N. dictyambonis*, *P. elongata* and *D. lichenoides*, which might be coeval with the upper sample of the present authors.

## AGE OF THE SZCZAWNICA FORMATION

(*by Przemysław Gedl*)

The Szczawnica Formation is a lithostratigraphic unit, formally described by Birkenmajer and Oszczypko (1989). It is distinguished in the Krynica Zone of the Magura Nappe (its southernmost facies zone) and on the folded Pieniny Klippen Belt. Formerly, these strata were distinguished by several authors under various names, e.g., the "nördliche Grenzbildungen" (Uhlig, 1890), the "Peri-Klippen Flysch" (Horwitz, 1935), the "Szczawnica Beds" (Birkenmajer, 1956b, 1957), the "Submagura Beds" and the "Beloveža Beds" (Bogacz and Węcławik (1962), the "Submagura Beds", the "Hieroglyphic Beds" and the "Inoceramus Beds" (Watycha, 1963b; Żytko, 1963; Alexandrowicz *et al*., 1966).

The age of the Szczawnica Formation studied by various authors for decades, although with differences in details, was accepted as Paleocene–Lower Eocene (e.g., Birkenmajer, 1962; Bogacz and Węcławik, 1962; Golonka and Waśkowska, 2014). This age was used widely in papers and schemes related to the geology of southernmost part of the Magura Nappe along its boundary with the Pieniny Klippen Belt (e.g., Michalik, 1963; Watycha, 1963a, b; Birkenmajer *et al*., 1965; Tokarski, 1975; Chrustek *et al.,* 2005; Oszczypko, 2008; Oszczypko and Oszczypko-Clowes, 2009; Oszczypko *et al*., 2015). Recently, however, Oszczypko-Clowes *et al.* (2018, and earlier papers therein) presented a different age interpretation of strata of the Magura Nappe, including the Szczawnica Formation, that crop out along the northern boundary of the Pieniny Klippen Belt and on it. On the basis of calcareous nannoplankton and foraminifera, they suggested a Lower Miocene age for the Jarmuta, Szczawnica and Magura formations and "reassigned" them to the Kremná Formation.

The studies of dinoflagellate cysts from the Szczawnica Formation and the Bryjarka Member from the PD-9 borehole by the present authors do not confirm their interpretations. All samples from the Bryjarka Member yielded rich assemblages that with no doubt are Eocene, most likely Early Eocene. Similar assemblages occur in the Szczawnica Formation from intervals 920–924.6 m, 866–869 m, and 729.1–850.6 m. The dinoflagellate cyst assemblages from these depths are uniform; they show no admixture of younger, Oligocene or Early Miocene forms that should be expected in the case of a Miocene age, as suggested by Oszczypko-Clowes *et al.* (2018). Moreover, a similar assemblage was described from the Jarmuta Formation at Czarna Woda

Creek, near Szczawnica, by Segit (in Jurewicz and Segit, 2018), who saw no signs of reworking; from the same locality, from which Oszczypko and Oszczypko-Clowes (2014) had described a single sample with calcareous nannoplankton, interpreted as Early Miocene (NN2 Zone).

In the opinion of the present author, a possible explanation for these differences in dating of the Szczawnica Formation is that the Early Miocene microfossils described by Oszczypko-Clowes *et al.* (2018) come from the youngest strata of the Magura Nappe, preserved as fragments along their contact with the Pieniny Klippen Belt but not from the Palaeogene formations. These Miocene strata represent the youngest parts of the Malcov Beds, which are widely known from the Polish and Slovak Magura Nappe (for details see Cieszkowski and Olszewska, 1986), as counterparts of the Oligocene–Miocene Menilite-Krosno series, known from more northerly nappes (the Malcov-Menilite series in Slovakia; Nemčok *et al*., 1968).

Age interpretations presented by Oszczypko-Clowes *et al*. (2018) are, in the opinion of the present author, over-interpreted in a form not supported by data for the whole Jarmuta, Szczawnica and Magura formations.

## TECTONICS IN DEEP BOREHOLE PD-9

The new biostratigraphic interpretations of the material studied by the present authors show only subtle changes to the interpretation of the vertical arrangement of rocks of the Grajcarek Main Dislocation in the PD-9 borehole presented by Birkenmajer *et al.* (1979). The most important change is in the re-interpretation of the age of the Bryjarka Member (415.0–702.0 m interval) and, as a consequence, its relocation from the Grajcarek Unit to the Magura Nappe. The other change refers to the age interpretation of the 729–850 m interval, which formerly was assigned to the Jurassic Szlachtowa Formation of the Grajcarek Unit (Birkenmajer *et al.,* 1979) and now is included in the Palaeogene Szczawnica Formation of the Magura Nappe.

The present and previous data (Birkenmajer *et al.,* 1979) show an almost vertical continuum of the Grajcarek Main Dislocation line at Szczawnica, at least to a depth of 1,200 m (Fig. 4). This vertical dislocation that separates the Magura Nappe (to the north) from the Grajcarek Unit of the Pieniny Klippen Belt (to the south) is disturbed by at least two major dislocations, along which subhorizontal displacements of the Magura Nappe and the Grajcarek Unit took place. These dislocations are associated with zones of intense brecciation that occur at depths of approximately 350 and 680 m (Fig. 4). The higher dislocation separates the overlying Grajcarek Unit from the Magura Nappe (Bryjarka Member). It is directly underlined by red shales of the Malinowa Shale Formation that owing to their relative softness commonly occur as “smear strata” at the main tectonic contacts.

The Grajcarek Main Dislocation shifts below this depth to the south, up to a depth of approximately 700 m, where another brecciation zone occurs. Directly beneath this, an interval of the Grajcarek Unit (Jurassic strata of the Szlachtowa Formation), several metres thick, occurs (Fig. 4). Below, another dislocation is indicated by the occurrence of the Palaeogene strata of the Magura Nappe (the Szczawnica Formation). Deeper still, the dislocation zone runs almost vertically; its trend shows a complicated tectonic engagement between the ductile shale of the Malinowa Shale Formation (the Grajcarek Unit) and the more rigid strata of the Magura Nappe (the Szczawnica Formation; Fig. 4).

The new biostratigraphic interpretations by the present authors of the strata penetrated by the PD-9 borehole shed new light on the tectonics of the Grajcarek Main Dislocation in the Szczawnica area. In general, the main characteristic of the dislocation zone there, compared to the interpretation proposed by Birkenmajer *et al.* (1979), remains the same, i.e., it clearly shows a steep, almost vertical course of the contact between the Magura Nappe and the Pieniny Klippen Belt. It supports earlier understanding of the tectonics of the Pieniny Klippen Belt and its relationship to the surrounding units, suggested by the senior author (e.g., Birkenmajer, 1965, 1985a, b, 1986; Birkenmajer and Gedl, 2012).

## CONCLUSIONS

The results of the analysis of dinoflagellate cysts from strata penetrated by the PD-9 borehole indicate some revisions with respect to earlier studies. They have to do with the ages of the Hałuszowa Formation, the Bryjarka Member and the Szlachtowa Formation and, as a consequence, a different tectonic interpretation of the strata in question.

1. The Campanian age of the Hałuszowa Formation originally was suggested by Birkenmajer (1977) on the basis of its superposition between the underlying Malinowa Shale Formation and the overlying Jarmuta Formation. It was generally confirmed by subsequent micropalaeontological studies: Senonian, on the basis of foraminifers (Jednorowska in Birkenmajer, 1979), late Senonian on the basis of calcareous nannoplankton (Dudziak in Birkenmajer, 1979), and Albian–early Campanian on the basis of dinoflagellate cysts (Gedl, 2007; for details see Birkenmajer and Gedl, 2017, p. 80). The interpretation by the present authors suggests upper Campanian–lower Maastrichtian age of at least a part of this lithostratigraphic unit. This range may indicate that the flysch and flyschoid facies of the Hałuszowa Formation partly overlap with the overlying coarse-grained Jarmuta Formation, the deposition of which started in the late Campanian–Maastrichtian (for details see Birkenmajer and Gedl, 2017).
2. The present authors downgrade the Bryjarka Member (formerly with the rank of formation) to the rank of member within the Szczawnica Formation. The latter, originally described as the Szczawnica Beds (Birkenmajer, 1956a, 1957) was described formally by Birkenmajer and Oszczypko (1989). The age of the Bryjarka Member is Early Eocene (Ypresian). This assumption is based on the rich dinoflagellate cyst assemblages found in core samples, which eliminates the risk of contamination inherent to bailer samples. As the oldest assemblages (early Ypresian) occur in the topmost part of this unit in the PD-9 borehole, the present authors suggest that this unit is either tectonically disturbed or that it occurs in an upside-down position. The Bryjarka Member was dated originally as Cretaceous by Dudziak (in Birkenmajer *et al*., 1979) on the basis of rare and poorly preserved, cal-

careous nannoplankton. The new age interpretation of the Bryjarka Member by the present authors makes this unit coeval with the Szczawnica Formation (see Birkenmajer and Oszczypko, 1989, tab. 1). Rich and uniform Early Eocene dinoflagellate cysts, found in both lithostratigraphic units, preclude the possibility of a Miocene age of them, as suggested by Oszczypko-Clowes *et al*. (2018).

3. The Szlachtowa Formation in the PD-9 borehole occurs at the depth 707.1–716.4 m only. Two samples from this unit yielded dinoflagellate cysts of late Toarcian–Aalenian age. Below, Lower Eocene strata, most likely of the Szczawnica Formation, occur (729.1–850.8 m). Formerly this interval was attributed to the Szlachtowa Formation (Birkenmajer *et al*., 1979). Dinoflagellate cysts from this interval show taxonomical similarities either with the ones from the Bryjarka Member and the Szczawnica Formation at the depths 866–869 m and 920.0–924.6 m.
4. Our new stratigraphic interpretation suggests slightly different tectonics of the northern boundary fault zone in the deep borehole PD-9 (Fig. 4) than it was proposed by Birkenmajer *et al.* (1979). The borehole runs down to the depth of ca 360 m through highly tectonized Upper Cretaceous strata of the Grajcarek Unit. Below, the main dislocation displaces to the south; it is manifested by a thick zone of intense brecciation at the depth of ca 360 m (Fig. 4). Below this depth, the borehole runs through Palaeogene strata of the Magura Nappe. Thin tectonic thrust sheets of the Grajcarek Unit (the Szlachtowa Formation and the Malinowa Shale Formation) that occur within the Palaeogene of the Magura Nappe down to the end of the borehole shows that the main dislocation has a steep, almost vertical dip at least up to the depth of 1,200 m.

## TAXONOMY OF SELECTED DINOFLAGELLATE CYSTS

### *Adnatosphaeridium* cf. *multispinosum* Williams et Downie, 1966

Fig. 7N–P

Two specimens of *Adnatosphaeridium* distinguished by relatively short processes (up to 10–12 µm) were found in the Bryjarka Member at the depth of 418.4–421.5 m (Tab. 1.40). They have been distinguished from *A. multispinosum* by shorter processes, which in the present material possess processes, which length oscillates between 12–14 and 25 µm.

In the original diagnosis of *A. multispinosum*, Williams and Downie (1966) estimate its process length up to 23 µm, without specifying its minimal length.

### *Apectodinium* cf. *homomorphum* (Deflandre et Cookson, 1955) Lentin et Williams, 1977

Fig. 12D, E

A species of *Apectodinium* characterized by relatively small, ovoidal pericyst (20 x 35 µm) and relatively long (10–15 µm) thick processes. Pericyst shape and process type identical to *A. homomorphum* except for their proportions. According to Harland (1979), *A. homomorphum* has pericyst that is larger (44–60 µm), whereas its processes are approximately of the same length as by the specimens determined as *A.* cf. *homomorphum* that occur in the Szczawnica Formation (Tab. 1.101).

### *Areoligera medusettiformis* (Wetzel, 1933) Lejeune-Carpentier, 1938 complex

Figs 6A, B, E– G, I, N–P, 11A, B, D, H, I, M–Q, S

Representatives of two morphologically similar species, *A. medusettiformis* and *A. coronata*, have been grouped in a complex. Distinguishing of the main difference between these two species – variable complexity of process expansion and their proximal membrane/ridges – in case of poorly preserved, commonly squeezed and folded specimens made their proper differentiation doubtful.

### *Deflandrea*? sp.

Fig. 12F–J

*Deflandrea* and other peridinioids are typically dorso-ventrally compressed, which makes that they usually appear in palynological slides in a dorso-ventral position. So it is in case of most peridinioids from the present material. But two samples from the Bryjarka Member (505.1–509.7 m and 584.3–589.1 m) yielded frequent peridinioid cysts, which are laterally positioned. Their frequency excludes an accidental mounting and reflects rather their unique lateral compression.

These forms, questionably included in the genus *Deflandrea*, are bicavate or circumvacate cysts, with one apical and two antapical horns. Apical horn is commonly terminated with tiny bulb. Endocyst ovoidal in lateral view, endophragm thick and smooth without parasutural features. Periphragm smooth, devoid of parasutural features except for occasionally poorly developed ridges in paracingular area. Periarchaeopyle in intercalary position, but owing to lateral position, its detail type and shape cannot be determined (this feature makes that these forms are assigned questionably to the genus *Deflandrea*).

### *Rhombodinium* cf. *longimanum* Vozzhennikova, 1967

Fig. 9L

A species of *Rhombodinium* resembling *R. longimanum* in general cyst shape, particularly by long lateral horns; it differs in its porous periphragm, which in *R. longimanum* is smooth to finely granulose (see Lentin and Vozzhennikova, 1990).

### *Rhombodinium* sp. A

Fig. 9Q

A single specimen was found in a sample from the depth of 426.3–431.1 m (Bryjarka Member). This large specimen shows no paratabulation features, except for the paracingular ridge. Archaeopyle is not visible. Periphragm bears infrequent, very short (1–2 µm) spikes. Orientation of the specimen illustrated (Fig. 9Q) is uncertain.

*Rhombodinium*? sp.
Fig. 11A, B

Two poorly preserved, incomplete specimens found in the Bryjarka Member (418.4–421.5 m and 505.1–509.7 m) have been questionably assigned to the genus *Rhombodinium*. Periphragm bears rare, scattered, short, solid processes, which are atypical for this genus.

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## Species list

An alphabetic index of dinocyst taxa found in the PD-9 borehole is provided below. Taxonomic citations can be found in Fensome *et al*. (2008).

*Achilleodinium*? sp. (Tab. 1.20)
*Achomosphaera alcicornu* (Eisenack, 1954) Davey et Williams, 1966 (Tab. 1.38)
*Adnatosphaeridium multispinosum* Williams et Downie, 1966 (Tab. 1.34; Fig. 6H, M)
*Adnatosphaeridium* cf. *multispinosum* Williams et Downie, 1966 (Tab. 1.40; Fig. 7N–P)
*Adnatosphaeridium vittatum* Williams et Downie, 1966 (Tab. 1.13; Fig. 6K)
*Alterbidinium*? sp. (Tab. 1.10; Figs 5I, J, 11E)
*Apectodinium homomorphum* (Deflandre et Cookson, 1955) Lentin et Williams, 1977 (Tab. 1.18; Figs 8G, 9C, H, I, 11T)
*Apectodinium* cf. *homomorphum* (Deflandre et Cookson, 1955) Lentin et Williams, 1977 (Tab. 1.100; Fig. 12D, E)
*Apectodinium parvum* (Alberti, 1961) Lentin et Williams, 1977 (Tab. 1.25; Figs 8H, J, K, 9F, G, 11U)
*Apectodinium quinquelatum* (Williams et Downie, 1966) Costa et Downie, 1979 (Tab. 1.42; Fig. 9D)
*Apectodinium summissum* (Harland, 1979) Lentin et Williams, 1981 (Tab. 1.32; Figs 8I, 9E)
*Apectodinium* sp. (Tab. 1.15; Fig. 11C)
*Apteodinium* sp. (Tab. 1.28; Fig. 7Y)
*Areoligera medusettiformis* (Wetzel, 1933) Lejeune-Carpentier, 1938 complex (Tab. 1.98; Figs 6A, B, E–G, I, N–P, 11A, B, D, H, I, M–Q, S)
*Areoligera* sp. (Tab. 1.17)
*Batiacasphaera* sp. (Tab. 1.91; Fig. 10A, B)
*Biconidinium longissimum* Islam, 1983 (Tab. 1.59; Fig. 8P)
*Circulodinium*? sp. (Tab. 1.4; Fig. 5B)
*Cordosphaeridium fibrospinosum* Davey et Williams, 1966 (Tab. 1.7; Figs 5L, M, 11Z)
*Cordosphaeridium inodes* (Klumpp, 1953) Eisenack, 1963 (Tab. 1.51; Fig. 7ZA)
*Cordosphaeridium*? *solidospinosum* Gedl, 1995 (Tab. 1.85)
*Cordosphaeridium* sp. (Tab. 1.26)
*Cribroperidinium* sp. (Tab. 1.60)
*Dapsilidinium* sp. (Tab. 1.84)
*Deflandrea eocenica* Balteş, 1969 (Tab. 1.76; Fig. 8N)
*Deflandrea leptodermata* Cookson et Eisenack, 1965 (Tab. 1.75; Fig. 8Q)
*Deflandrea oebisfeldensis* Alberti, 1959 (Tab. 1.70)
*Deflandrea* sp. (Tab. 1.61; Figs 8M, U–W, X, 12C)
*Deflandrea*? sp. (Tab. 1.67; Fig. 12F, G–J)
*Dinogymnium acuminatum* Evitt *et al*., 1967 (Tab. 1.83)
*Dinogymnium* sp. (Tab. 1.6; Fig. 5F)
*Diphyes colligerum* (Deflandre et Cookson, 1955) Cookson, 1965 (Tab. 1.49; Fig. 7A, B)
*Dissiliodinium* sp. (Tab. 1.92; Fig. 10V)
*Distatodinium ellipticum* (Cookson, 1965) Eaton, 1976 (Tab. 1.107)
*Dracodinium condylos* (Williams et Downie, 1966) Costa et Downie, 1979 (Tab. 1.102)
*Dracodinium laszczynskii* Gedl, 1995 (Tab. 1.54; Fig. 8L)
*Dracodinium solidum* Gocht, 1955 (Tab. 1.86)
*Dracodinium waipawaense* (Wilson, 1967) Costa et Downie, 1979 (Tab. 1.44; Fig. 9T)
*Dracodinium* sp. (Tab. 1.50)
*Eocladopyxis*? sp. (Tab. 1.108)
*Escharisphaeridia*? sp. (Tab. 1.58)
*Glaphyrocysta exuberans* (Deflandre et Cookson, 1955) Stover et Evitt, 1978 (Tab. 1.47; Fig. 6S)
*Glaphyrocysta laciniiformis* (Gerlach, 1961) Stover et Evitt, 1978 (Tab. 1.22)
*Glaphyrocysta ordinata* (Williams et Downie, 1966) Stover et Evitt, 1978 (Tab. 1.39)
*Glaphyrocysta spineta* (Eaton, 1976) Stover et Evitt, 1978 (Tab. 1.23; Fig. 6T)
*Glaphyrocysta* sp. (Tab. 1.8; Figs 5N, 6Q, R,)
*Gonyaulacysta* sp. (Tab. 1.46)
*Heslertonia heslertonensis* (Neale et Sarjeant, 1962) Sarjeant, 1966 (Tab. 1.53)
*Heteraulacacysta leptalea* Eaton, 1976 (Tab. 1.66)
*Homotryblium abbreviatum* Eaton, 1976 (Tab. 1.48; Fig. 7Q)
*Homotryblium caliculum* Bujak, 1980 (Tab. 1.36)
*Homotryblium pallidum* Davey et Williams, 1966 (Tab. 1.45; Fig. 7S)
*Homotryblium tenuispinosum* Davey et Williams, 1966 (Tab. 1.12; Figs 7R, V, 11R)
*Hystrichodinium*? sp. (Tab. 1.79)
*Hystrichokolpoma* sp. (Tab. 1.69)
*Impagidinium velorum* Bujak, 1984 (Tab. 1.64)
*Impagidinium* sp. (Tab. 1.81; Fig. 7W)
*Impletosphaeridium* sp. (Tab. 1.52)
*Isabelidinium*? sp. (Tab. 1.16; Fig. 8O, R–T)
*Kallosphaeridium praussii* Lentin et Williams, 1993 (Tab. 1.90; Fig. 10C, D)
*Kallosphaeridium*? sp. (Tab. 1.89; Fig. 10P, W)
*Lejeunecysta* sp. (Tab. 1.35)
*Lingulodinium machaerophorum* (Deflandre et Cookson, 1955) Wall, 1967 (Tab. 1.33)
*Lithodinia* sp. (Tab. 1.105)

*Melitasphaeridium asterium* (Eaton, 1976) Bujak *et al*., 1980 (Tab. 1.82)

*Melitasphaeridium pseudorecurvatum* (Morgenroth, 1966) Bujak *et al*., 1980 (Tab. 1.57; Fig. 7C)

*Muderongia*? sp. (Tab. 1.5; Fig. 5C)

*Nannoceratopsis dictyambonis* Riding, 1984 (Tab. 1.87; Fig. 10F, G, K, U)

*Nannoceratopsis gracilis* Alberti, 1961 (Tab. 1.88; Fig. 10I, L, N, O, T, X–Z)

*Nannoceratopsis raunsgaardii* Poulsen, 1996 (Tab. 1.94; Fig. 10M)

*Nannoceratopsis spiculata* Stover, 1966 (Tab. 1.93; Fig. 10ZA, ZB)

*Nannoceratopsis* sp. (Tab. 1.95; Fig. 10E, H, J)

*Nematosphaeropsis reticulensis* (Pastiels, 1948) Sarjeant, 1986 (Tab. 1.72; Fig. 7H, I)

*Odontochitina* sp. (Tab. 1.103)

*Operculodinium divergens* (Eisenack, 1954) Stover et Evitt, 1978 (Tab. 1.71; Figs 6L, 7U)

*Operculodinium microtriainum* (Klumpp, 1953) Islam, 1983 (Tab. 1.19; Figs 7ZB. 11V)

*Operculodinium* sp. (Tab. 1.41; Figs 6C, 7G, X, 11L)

*Ovoidinium*? sp. (Tab. 1.2)

*Palaeocystodinium golzowense* Alberti, 1961 (Tab. 1.99)

*Palaeohystrichophora infusorioides* Deflandre, 1935 (Tab. 1.109; Fig. 11J)

*Phallocysta elongata* (Beju, 1971) Riding, 1994 (Tab. 1.96; Fig. 10Q)

*Phallocysta* sp. (Tab. 1.97; Fig. 10R, S)

*Phthanoperidinium delicatum* Michoux, 1985 (Tab. 1.11; Figs 8A, B, E, 11K)

*Phthanoperidinium* sp. (Tab. 1.56; Fig. 8C)

*Polysphaeridium subtile* Davey et Williams, 1966 (Tab. 1.55; Fig. 7F)

*Polysphaeridium zoharyi* (Rossignol, 1962) Bujak *et al*., 1980 (Tab. 1.14; Fig. 7D, E, K)

*Pterodinium* sp. (Tab. 1.3; Fig. 5K)

*Rhiptocorys* sp. (Tab. 1.112)

*Rhombodinium* cf. *longimanum* Vozzhennikova, 1967 (Tab. 1.77; Fig. 9L)

*Rhombodinium* sp. A (Tab. 1.43; Fig. 9Q)

*Rhombodinium* sp. (Tab. 1.62; Fig. 11W)

*Rhombodinium*? sp. (Tab. 1.30; Fig. 12A, B)

*Rottnestia borussica* (Eisenack, 1954) Cookson et Eisenack, 1961 (Tab. 1.74; Fig. 7L)

*Senegalinium*? sp. (Tab. 1.78; Fig. 8F)

*Spinidinium* sp. (Tab. 1.72; Fig. 8D)

*Spiniferites pseudofurcatus* (Klumpp, 1953) Sarjeant, 1970 (Tab. 1.106)

*Spiniferites* sp. (Tab. 1.1; Figs 5A, G, H, 7J, M, 11F, G)

*Subtilisphaera*? sp. (Tab. 1.104)

*Surculosphaeridium* sp. (Tab. 1.110)

*Systematophora* sp. (Tab. 1.27; Fig. 6D)

*Tectatodinium*? sp. (Tab. 1.37)

*Thalassiphora patula* (Williams et Downie, 1966) Stover et Evitt, 1978 (Tab. 1.24; Figs 6J, 7Z)

*Thalassiphora* sp. (Tab. 1.63; Fig. 11Y)

*Trithyrodinium*? sp. (Tab. 1.65)

*Wetzeliella astra* Denison in Costa *et al*., 1978 (Tab. 1.68; Fig. 9A, B, P)

*Wetzeliella meckelfeldensis* Gocht, 1969 (Tab. 1.29; Fig. 9U)

*Wetzeliella unicaudalis* Caro, 1973 (Tab. 1.80; Fig. 9K)

*Wetzeliella* sp. (Tab. 1.21; Fig. 9J, M–O, R, S)

*Wilsonidinium*? sp. (Tab. 1.101)

*Wilsonidium intermedium* (Cookson et Eisenack, 1961) Costa et Downie, 1979 (Tab. 1.111; Fig. 11X)

*Ynezidinium brevisulcatum* (Michoux, 1985) Lucas-Clark et Helenes, 2000 (Tab. 1.31; Fig. 7T)

*Yolkinigymnium* sp. (Tab. 1.9; Fig. 5D, E)

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